TOPICS OF THE MONTH

What's in a name?

WHEN confronted by the public ignorance about his true function the chemical engineer is often tempted to change his name.

> What's in a name? That which we call a rose
> By any other name would smell as sweet.

Age-old definitions of a chemical engineer as either a chemist who knows no engineering or an engineer who knows no chemistry are still seriously discussed by people with very little notion of the true status of this hybrid technologist. Yet, once more to define what a chemical engineer really is would be preaching to the converted.

That there is a dire shortage of chemical engineers is well known and has been publicised adequately for many years. The result of this publicity has been intervention by both government and large industry in the establishment of more and larger departments of chemical engineering at universities and technical colleges. This, together with the bestowal of a royal charter on the Institution of Chemical Engineers, has underlined the importance of the fourth primary technology. Yet, in spite of all this, the prevailing ignorance in industry about the correct application of chemical engineering principles to various problems is astounding. This combination of marked official approval coupled with private ignorance is one of the most frightening realisations with which the young graduate chemical engineer is confronted when he enters industry. No wonder he is tempted to change his name or, what is worse, to forget and forego his principles.

A missionary zeal is very often required to overcome this. Is not the training that the chemical engineer receives both widely based and profound? It ranges over the gamut of chemistry, mechanics, thermodynamics and physics, as well as applying fundamental laws from these sciences to particular problems encountered in chemical processes and the design of chemical plant. Thus the chemical engineer can acquire a broad scientific culture to which chemistry or engineering students can never aspire. Surely his first effect on industry should be to distinguish himself by his broadly based outlook towards the chemical industry. Not only is he capable of understanding the chemical and physical reactions in processes, but as a result of this understanding he can design plant more efficiently.

The concept of unit operations is probably the best illustration of the contribution of chemical engineering science to industry. However, a wider application of unit operations to branches of the chemical industry hitherto uncharted by the chemical engineer is urgently needed. It is a fact that the large majority of chemical engineers are employed in the petroleum, heavy chemical and design industries. Very few are found in the smaller branches like rubber, plastics and food. Yet these industries could profit most from a fundamental application of unit operations. As an example there is the study of extrusion and mixing widely used in the rubber and plastics industry which, if properly analysed and studied on chemical engineering principles, would yield very interesting information most certainly resulting in better designed plant.

We feel, therefore, that it is now up to the chemical engineer to sell himself and make his presence vital in every branch of industry. Once that happens there will be very little temptation for him to change either his name or to re-adapt himself as a second-class chemist and engineer.

Temperature control

THAT objects often possessed different temperatures must have been appreciated by the inhabitants of the world long before the dawn of history. Temperature measurement as an empirical art may be said to have begun with the desire to express temperature differences more precisely than by mere comparisons such as, for instance, cold (winter in England), colder (winter in Scotland) and coldest (winter in Iceland). Aristotle ascribed four qualities that are possessed by all matter: heat, cold, moisture and dryness. He did not, it would appear, suggest any method of defining the relative proportions of each quality.

The ancient medical practitioner and writer Galen, described conditions of heat and cold by numbers. He suggested that there was an 'equal temperature' which was the normal one for the person or animal concerned, and this he considered to vary from one person to another. As the writings of Galen formed the foundations of medical thought throughout the Western world for the next 1,500 years, the ideas of degrees of heat and cold (that is, graduations and not present-day conceptions of degrees) became generally accepted in medical literature. Few writers at that time attempted to attach a more accurate meaning to these numbers.

With the dawn of the Newtonian age, thermometry was required for purposes other than measuring the conditions of the human body. It became one of the few accurate means of verifying or disproving physical laws. As a result, a systematic scale had to be devised and, what is of more importance, results had to be reproducible.

The astounding development in thermometry during this century is, of course, only a reflection of the current progress of science and technology. Yet, as readers will note in this month's special feature, many new temperature measuring devices are so elegant in their own right that it is often astonishing to reflect that they are really only designed as 'handmaidens' of science.

Fuel and power v. natural prosperity

WHAT is the cause of the phenomenal rise in the living standards of the Western world during the past 50 years? This has been debated by historians, sociologists, politicians and, not least, scientists and engineers. Few pundits will dispute the date of birth of this event; sometime during the industrial revolution of the 19th century. Yet, whilst intriguing hypotheses have been put forward trying to explain historico-sociological forces which made it imperative for Europe to beget this offspring, fewer efforts have been spent in explaining how the baby grew up to maturity and has become a veritable Samson.

In the first of the Cantor lectures at the Royal Society of Arts, Dr. A. Parker, lately director of fuel research at the D.S.I.R., attributed this unprecedented growth to the Western world's effective use of fuel and power in overcoming climatic disadvantages, in manufacturing materials and in greatly augmenting human labour. It has been shown that countries with the highest standard of living have the highest fuel and power consumption per head of population. Thus the United States, with an annual average income of £730 per inhabitant, has, an annual average fuel consumption of 8.6 tons per inhabitant, in the U.K. the figures are £532 income and 8.3 tons fuel consumption, whilst India has £18 income and 0.1 tons fuel consumption.

The total resources of fossil fuels were shown by Dr. Parker to be nearly equivalent to 5 million million tons of bituminous coal. Of this quantity, 92% occurs as coals and lignites and 6% as petroleum, natural gas and methane. As against these conventional fuels, it has been estimated that the energy value of available reserves of uranium and thorium are probably 25 times as great! It is clearly evident, therefore, that the problem facing the world is not due to a shortage of total energy resources, but in harnessing those resources at reasonable cost to meet the rapidly growing needs of an expanding world population. At present the world relies mainly on the use of fossil fuels for heat and power. These fuels are being used up faster than they are produced in nature, and are not always conveniently accessible. The main question is, how long will the economically recoverable reserves of fossil fuels meet total world needs, and will economic methods of harnessing the other resources of energy be developed before conventional fossil fuels are exhausted?

It is impossible to forecast how this dilemma will be resolved. Yet, if world population and energy demand continues to increase at the same average geometric rate as during the past 20 years, then by the year 2,000 the population will be about 5,000 million and the annual energy demand about 17,500 million tons equivalent of coal; whereas the present population is 2,850 million with an annual energy consumption of 4,550 million tons equivalent coal.

However, most factors tend to show that it should not be readily assumed that the rate of increase in world energy demand will continue for more than another few decades. There is bound to be an increase. On the other hand, the known reserves of fossil fuels, hydro-electric potential and nuclear fuels will ensure an adequate supply for the world until further reserves are discovered, and economic methods of generating and harnessing energy have been developed.

Chemistry and university

PROF. T. L. COTTRELL certainly set the cat amongst the pigeons in his inaugural lecture delivered to the University of Edinburgh last November. ' My main personal impression,' he said, ' is that the most striking characteristic of the chemist in industry is his lack of professional competence.' He based this accusation on three defects from which industrial chemists seem to suffer, the lack of power to apply theory, the lack of critical approach to the problem in hand, and the inability to communicate clearly; to be summed up as a lack of academic approach. This may lead to the seemingly paradoxical conclusion that the greatest practical defect of the professional chemist is a lack of academic intellectual qualities.

This criticism strikes directly at the root of a problem of our times. As the chemical industry expands there is a growing need for every type of chemist, pure or applied. Where are these scientists and technologists to be trained? The universities have for long been the traditional training ground for scientists and engineers, and have comparatively recently opened their doors to technology. They claim, and rightly so, that their function is purely academic: to act as the keeper of the nation's intellect. By their very constitution they must pursue knowledge and learning for its own sake. That the fruit of this learning should ever become of practical interest to industry is of secondary importance to them. Why does industry now commission them to mass-produce industrial scientists? He who pays the piper calls the tune, and there is surely no doubt that, since the end of the war, industry has been a most magnanimous payer.

By comparing the funds available to arts faculties with those of science and engineering faculties this point is brought home impressively. Yet the piper has so far not specified precisely what his tune is. To begin with there is the short-term policy of turning out ever more graduates. How can these graduates best be trained to equip them to solve industry's multifarious problems? The fact that this has never been examined properly has led to the many inadequacies pointed out by Prof. Cottrell. Failure to resolve this state of affairs must be apportioned as much to the universities as to industry. Most faculties of chemistry have been gladly accepting industrial endowments but have altered their undergraduate courses very little.

The snobbish attitude towards applied science with which many students are still confronted by their teachers at university is sufficient proof of that. Many of them still treat their final-year class as just a con-

venient sludge from which to extract the two or three promising research men. The rest are, in their opinion, a waste of academic time. Has this not tended to foster a dislike in the minds of most graduates against the academic approach, which they subconsciously identify with the unpractical way of dealing with a problem ?

As a remedy to this, Prof. Cottrell suggested that a complete reappraisal of the time-table be undertaken with a view to stressing those parts of the curriculum that would be of permanent benefit to the chemist, as opposed to the manipulative skills of the laboratory technician. Obviously this is one step in the right direction. However, before the universities themselves have not resolved the fundamental problem of where they stand with regard to the training of scientists, no satisfactory solution can be expected.

Materials of construction

AT first sight it could be argued that any series of articles dealing with materials of construction must of necessity be well-known variations on a quite unoriginal theme. The proposed theme, we admit, is not original but we do claim a certain amount of originality for the variations. During his training every chemical engineer is impressed with the importance of selecting the right material for the right job. Yet in view of the dearth of comparative data available, proper selection is made generally by a combination of experience and intuitive guessing which is only acquired after long years of experience and learning from past errors.

We have therefore planned an extensive series dealing with each material of construction separately. Contributors who have been selected from research associations and industrial undertakings were asked to write their articles around certain terms of reference which are given in the introduction. Thus we hope to obtain useful comparative data between conventional and more novel materials of construction, and also to gauge the value of these materials from the critical assessment made. Such a comprehensive treatment is not only invaluable but is bound also to generate strong feelings in many quarters. We cordially invite readers to comment to us on these articles and hope in this way to throw even more light on the whole subject.

Light-weight cooling tower

A NEW design for a cooling tower weighing less than half as much as conventional towers of similar capacity was recently announced by Thermotank Ltd. The considerable saving in weight and size is achieved by using a lightweight fill material in which the water is cooled by a counter-current of air as it passes through very closely spaced elements. The fill, made from a phenolic-impregnated cellulose material, is arranged in a honeycomb structure of alternate flat and corrugated sheets. By making this into rigid units which only require a very light supporting structure at the base, the entire internal area of the tower can be occupied by the fill without need for bracings.

The tower, which is circular in shape, contains a top-mounted fan which draws the surrounding air up through it from the bottom. The fill is arranged across the inside of the tower, with the channels disposed vertically, and the cooling air passes up through these channels. Water enters the tower at the top and is distributed across the surface of the fill by a centrally mounted rotating header pipe containing a number of perforations along its length through which the water streams on to the fill.

In view of the high wettability of the fill, the water passes down the walls of the channels in a thin, continuously moving film. This ensures maximum area of contact between the rising currents of air and water, thus utilising the volume of fill to its greatest capacity. A catchment tray at the base of the tower collects the cooled water for return to the process for which it is required.

The actual cost of such a tower has not been revealed. It is not expected to be less than that for conventional towers; if anything even more (development costs are claimed to have been exceedingly high). Potential buyers of water-cooling plant may well hesitate before investing in this newly designed tower if they find no appreciable saving in initial cost price.

Irradiated leather

THE British Leather Manufacturers Association, in collaboration with the isotope research division, Harwell, has been investigating the possibilities of using massive radiation doses to cure hides and skins. The mechanism of curing in the leather industry has changed very little for hundreds of years. After the animal has been flayed immediate attention must be given to arresting the putrefaction, caused by bacterial action, which begins almost instantaneously. At present, there are two main ways of doing this. The material may simply be dried in the sun until it becomes stiff like a board. This method is usually adopted in tropical countries and, while it is effective, it suffers from the disadvantage that it lowers the potential quality of the finished leather. The other method, which has a number of variations, is to use salt. There has been much research into the best type of salt to use for different classes of rawstock and the best methods of applying it. It is generally agreed, however, that salting has certain disadvantages, although it is greatly to be preferred to drying.

The possibility of using radiation techniques in place of salting as a method of preservation was first considered by B.L.M.R.A. in 1955. It was found that the most satisfactory rays were x- and γ-rays. The main advantages of irradiation are:

(1) Highly efficient inactivation of micro-organisms and other forms of life is possible.
(2) An appreciable thickness of material can be treated in diverse containers.
(3) The process lends itself readily to continuous operation.

Some disadvantages of this method are that the cost of the process depends upon its continuity, the most economical method necessitating 24-hr. operation. Also the minimum radiation dose necessary (2½ million rads) causes some loss in strength of the skin fibres and a fall in shrinkage temperature.

Taking a long-term view, it is of interest that a process modification which might arise in the future as a result of using irradiation is the partial elimination of liming. For hundreds of years this has been an essential feature of the leather-making process; its purpose is to facilitate the removal of hair and unwanted proteins before tanning begins. In recent years much attention has been given to the elimination of this process, which gives rise to troublesome effluent problems.

It appears, however, that radiation may not generally be adopted as a curing method for some time to come. This is very largely a result of economic considerations, which means that the expensive plant could only be used at one or two major centres, an unsuitable arrangement for a highly dispersed industry. On the technical side, although there are some difficulties to be overcome, there is nothing to suggest they are insuperable and, provided the economic picture changes, further developments would be likely.

CONSORT for Imperial College

A NEW nuclear research reactor, CONSORT, has been designed jointly by the G.E.C.-Simon-Carves atomic energy group and the nuclear power group at the Imperial College of Science and Technology. This collaborative approach has resulted in a design particularly suitable to meet the specialised requirements of universities.

CONSORT was designed primarily as a source of neutrons for use in experimental work for research purposes. The rating of the reactor for continuous operation is 10 kw. and, at this power level, a flux of approximately 3×10^{10} thermal neutrons and 2×10^{10} fast neutrons/sq.cm./sec. is available at an experimental face in the wall of the reactor tank adjacent to the core. A similar flux can also be obtained at the inner face of a graphite thermal column on the opposite side of the tank.

The cost of this reactor will be about £50,000. CONSORT combines some of the principal advantages of the two well-known existing types of water-moderated research reactors, the ' swimming-pool ' type and the ' enclosed-tank ' type. In the former design, the reactor core is housed in a large tank of water at a substantial depth below the surface so that the water itself provides all the shielding necessary above the core. This arrangement offers the advantages of good accessibility and ease of handling of the fuel elements. The enclosed-tank reactor uses a comparatively small tank of water with concrete shielding above the core as well as round the sides. The whole assembly is more compact than the swimming-pool type, with the result that it is much easier to locate external experimental assemblies close to the core.

Sea-water desalination

IT is well known that by freezing an unsaturated brine solution pure ice crystals are formed. This well-known physico-chemical principle was recently applied to desalination of sea-water by the Israeli engineer A. Zarchin. His process is based on separation of fresh water from brine by fractional crystallisation. Sea-water to be desalinated is passed into a high-vacuum evaporator where it is partially vaporised. This causes the bulk temperature of the solution to drop and, as a result, partially freeze. The salts from the sea-water accumulate in the liquid phase, giving a highly concentrated brine which is discarded. The solid phase containing pure ice crystals is brought into contact with the previously extracted vapours and melted, to give desalinated fresh water suitable for irrigation, industry and drinking purposes. Preliminary cooling of the sea-water is obtained by passing this, with the concentrated brine, through a heat exchanger.

The American company, Fairbanks-Whitney, has shown interest in this process and has decided to take up its commercial exploitation. With this end in view three engineers from Fairbanks-Whitney will shortly be arriving in Israel in order to design and erect a semi-industrial plant in Eilat on the Red Sea. It is estimated that this will take at least two years. Only then will it be possible to calculate the real cost of desalination per cubic foot of sea-water. It is thought at present that if developments go according to plan the cost of fresh water by the Zarchin process should be significantly cheaper than any other known method used at present. It is to be hoped that trials will be completed soon.

Painters' paradise

ON first seeing Raphael's St. Cecilia at Bologna in 1525, Antonio Corregio was heard to mutter: ' I too am a painter.' History has proved this no vain boast, yet we may be tempted to ask why did the renowned Corregio have to justify himself before the arbiters of painting? The only satisfactory answer seems that the age-old malaise of whatever-you-can-do-I-can-do-better had afflicted even him.

No doubt this malaise must affect lesser men, possibly whilst viewing some of the frequently exhibited masterpieces painted by presidents and retired prime ministers. To this we can attribute a recent pronouncement by the American Chemical Society that it will hold an exhibition of paintings by chemists and chemical engineers this summer. We have been assured that an award will be made for the best painting, though unfortunately the nature of this award has not been revealed to us. May we suggest that this should be a free trip to Bologna including a private showing of Raphael's masterpiece, this to be followed by the recipient's impression of it in one sentence. As a counter-attraction it should be possible to hold an exhibition of chemical plant designed by eminent artists. We can envisage entries by Picasso and Heath Robinson. Readers are invited to submit suggestions for suitable awards.

Separation of Mixed Minerals

By A. E. Williams, Ph.D., F.C.S.

There are essentially two different methods used for separating mixed minerals: gravity concentration and magnetic processes. Due to the increasing demand for minerals having exceptionally high physical properties, new developments in separation techniques have been applied recently. This article describes several currently known processes and gives a short account of a typical American minerals recovery plant for titanium.

THE rapidly increasing demand for minerals which hitherto have been of little importance is largely the result of developments in the nuclear power and aircraft industries. To meet the requirements of these industries, equipment has been designed which enables mineral deposits to be economically exploited. Natural deposits of minerals invariably occur as mixtures, in which perhaps one or several of the ingredients may be required. The characteristic properties of each ingredient enables them to be separated by such processes as gravity concentration, based on the densities of the minerals. Minerals roughly separated in this way can be further separated by magnetic processes which distinguish between conductors and non-conductors, and the varying degrees of magnetism, in different minerals. Allied to magnetic techniques is the high tension separation process for isolating negatively charged from positively charged particles. By the use of these separation methods, practically all minerals can be isolated from each other. In general, the preliminary separation is always accomplished by the use of a gravity concentration technique. A modern example of the latter, and one which supersedes the time-honoured settling tables, tanks, etc., is the fanning ore concentrator which has been developed in the United States.

The fan concentrator unit in Fig. 1 embodies a complete outfit for undertaking gravity separation tests and includes sump, motor and pump with variable-speed drive. The material to be separated is introduced as a pulp of high density, usually about 65% solids, into a rising column that increases in area as it rises. From this column the pulp flows over a feed lip at a very low entrance velocity into a sluice. As the material flows down the sluice, the speed of the flow at the top of the thick pulpy bed increases, and the speed of the flow decreases at the bottom of the sluice towards which
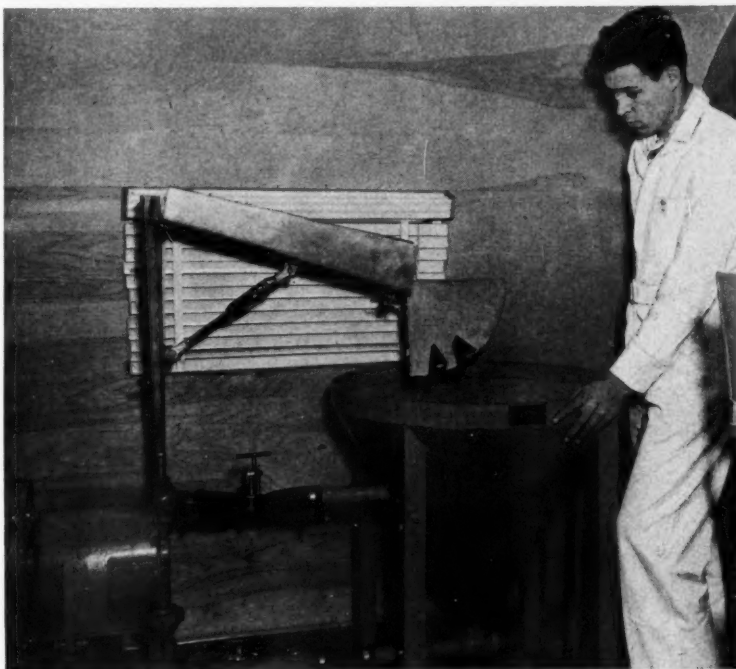

Fig. 1. Fan-type ore concentrator for pilot plant separations.

the heavier minerals migrate. The effect of this separation is enhanced by narrowing the lower end of the chute to a high narrow discharge, thus giving a pinched sluice effect. The material discharged from the sluice is fanned out on a rubber-coated plate where the material acts very much as if it were given a twirl on a vaning plaque. The light minerals being on top and in the faster-moving water, travel farthest across the plate, while the heavier minerals coming from the bottom of the sluice with minimum velocity quickly lose their forward motion and discharge off the back section of the plate. Tailing, middling and concentrate portions of the fanned-out mineral stream are separated by neoprene rubber wedges to yield separation products.

A feature of the fan concentrator

which has been experienced in industrial scale practice is that its capacity increases as the amount of heavy mineral in the feed increases. Many of the older type of gravity concentrators have high capacity on feeds containing small quantities of heavy minerals, and in general tend to decrease in capacity as the heavy mineral content of the feed increases. The fan concentrator, on the contrary, requires a high density of feed regardless of the nature of the materials being handled and, therefore, has an increasing capacity as the stages of concentration increase. This feature allows the use of comparatively few units in the recleaning stages of concentration. It also permits the fan concentrator to be a secondary and final concentrator following other separating equipment which is most

suitable for making bulk rougher concentrates at high tonnage rates.

Small-scale unit

As the fan concentrator is essentially a semi-mobile unit and much smaller than other gravity separation units, it may be used with great advantage in isolated places when mineral prospecting. This saves time in sending back samples to laboratories which may be hundreds of miles away, and awaiting the results of the laboratory test. In using this unit, the required amount of feed is added to the sump to give the density of feed most suitable for that material. Optimum separation conditions can be set up, with the separated products returning to the sump in a closed circuit. On small samples, closed circuit tests are usually satisfactory. In pilot plant tests, when separating material at the rate of up to 2 tons/hr., the concentrate and tailings products are removed by the use of small launders, and an equivalent amount of feed added at a continuous and steady rate. Feed rate is controlled by a pinch valve on a by-pass from the discharge of the pump to the sump. A large quantity of the material being pumped is discharged back into the sump at high pressure. Such a by-pass provides control of the feed rate to the concentrator as well as creating violent turbulence in the sump, which, in turn, ensures uniform pulp density. Pulp density is controlled by the amount of solids introduced into the sump in closed-circuit testing, but in normal operation for production, water and minerals are both added to the sump at the same rate as they are being taken away as separated products.

Fan orientation in relation to sluice discharge is entirely variable, since the fan-supporting members act as a universal joint. The angle at which the material hits the fan largely determines the quality of separation attained. In normal operation, the neoprene rubber wedges are set to give concentrate, middling and tailing products.

Magnetic properties

Minerals fall broadly into two classes, conductors and non-conductors, and both these may be sub-divided into magnetic and non-magnetic minerals. It is such properties of minerals that enable electric currents, applied through appropriate equipment, to separate one from the other. Tables 1 and 2, the result of work done in the research laboratories of Carpco Manufacturing, Inc., give the separation characteristics of typical minerals.

Starting with a mixture of the minerals tabulated, it may be determined whether or not they can be separated by high tension, magnetic or gravity methods; and whether any one or a combination of methods is required. If the minerals appear in different columns, they may be separated by high-tension and/or magnetic methods alone. Two or more minerals appearing in the same column can be separated by gravity concentration if they have sufficient difference in gravity; usually a difference of at least 1.0 is necessary. The size and shape of the mineral particles may sometimes affect the separation characteristics. This is sometimes detrimental and at other times useful. For example, mica and quartz, although having specific gravities close to one another, may be separated by high-tension methods due to the difference in grain shape.

Magnetic separators

The well-known mineral rutile, which is a natural form of titanium dioxide and a source of titanium metal, affords an example of the use of magnetic separators. Rutile is often found in admixture with minerals such as monazite, zircon, sillimanite, etc., all of which, except monazite, are either non-magnetic or weakly magnetic. To obtain a relatively clean rutile from such a mixture, use is made of a high intensity induced roll magnetic separator (Fig. 2) (often used in the form of three-rotor units). In this arrangement, each unit consists of a single separating rotor operating in a complete magnetic circuit and, as such, each unit is a complete magnetic separator in itself. The units may be operated separately or combined to make up machines of considerable capacity. This unitised construction allows the highest obtainable flux densities to be applied; individual control of the flux density in each rotor is possible. This also gives maximum flexibility in the different minerals which can be handled.

When using three rotors one above the other, having the same base and drive, optimum metallurgical results can be obtained by using the top rotor as a rougher, and the centre and bottom rotors as magnetic and non-magnetic product recleaners. A machine operating in this way gives fairly high purity in the minerals separated. The design of modern machines of this type is directed towards obtaining clean separators at high feed rates, as well as being able to separate materials of very low magnetic susceptibility. With this object in view, all the steel-to-steel joining sur-

Table I. Separation characteristics of non-conductors

Specific gravity	Magnetic	Weakly magnetic	Non-magnetic
6.0	—	—	Scheelite
5.2	Monazite	Bastnasite	—
4.6	Xenotime	—	Zircon
4.0	Garnet	—	Barite
3.6	Siderite	—	Corundum
3.5	Staurolite	Epidote	Kyanite
3.4	—	Olivine	Diamond
3.3	—	Apatite	Topaz
3.2	—	Hornblende	Sillimanite
3.0	—	Tourmaline	Fluorite
2.8	—	Mica (Biotite)	Mica (Muscovite)
2.5	—	—	Feldspars
2.4	—	—	Calcite
2.3	—	—	Quartz
2.1	—	—	Gypsum
2.0	—	—	Chrysolite
1.9	—	—	Sulphur

Table 2. Separation characteristics of conductors

Specific gravity	Highly magnetic	Magnetic	Weakly magnetic	Non-magnetic
Over	—	—	—	Gold
8.0	—	—	—	Copper
7.5	—	Ferberite	Wolframite	Galena
7.4	—	—	—	Cassiterite
6.1	—	—	Columbite	—
6.0	—	—	Tantalite	—
5.0	Magnetite	—	Samarskite	—
4.9	—	—	Euxenite	Pyrite
4.7	Ilmenite	Ilmenite	Hematite	Molybdenite
4.5	(high iron)	Davidite	Chromite	—
4.2	—	—	—	Rutile
4.1	—	—	—	Chalcopyrite
3.9	—	—	—	Brookite

faces in the magnetic circuit are wet-ground and polished; while the nose-piece and tail-piece contours are accurately machined to permit minimum rotor air-gaps. Due to the particular pole-piece design and the method by which these poles approach the rotor, flux densities acting on the mineral particles during their entire travel path on the surface of the rotor are considerably above the saturation of the magnetic components of the separator. The latest types of these machines are designed to saturate the core pieces at 100,000 lines of force/sq.in. Also, an over-saturated condition exists in the mineral separation air-gap of 156,000 lines of force/sq.in. at maximum flux settings. This gives a total of 3,600,000 lines of force available for mineral separation in each rotor unit. To avoid dilution of the magnetic power created, the surrounding metal components are made of non-magnetic materials, so that all the magnetic force present is put to full use by passing through the mineral separation air-gap, with only a minimum of stray magnetic forces. Moreover, the framework of the machines is not required to do double duty in handling magnetic flux and simultaneously acting as a structural member. Since very high forces act on the separating rotor, heavy-duty double spherical roller bearings are used. These are attached by non-magnetic heavy bearing blocks directly to the core structure. This is done because any attempt to mount these bearings on the framework of the machine would cause structural distortion at the high magnetic flux densities for use with certain classes of minerals.

Adjusting magnetic force

The magnetic force acting on the minerals as they pass through the rotor air-gap is controlled by raising or lowering the nosepiece. The magnetic flux which flows through the entire circuit varies inversely as the square of the total air-gap area. Generally speaking, the widest air-gap would be employed which would give enough magnetic force to separate the minerals. As the air-gap is widened, the amount of material that can pass through the gap is increased, thereby giving a higher feed rate. Narrow gaps creating a high flux density in the rotor require more power to turn the rotor, and more heat is created by magnetic hysteresis in the rotor itself. In practice, gap spacing is kept as wide as possible to allow an optimum separation of the minerals. This gives high feed rates, low temperature rises
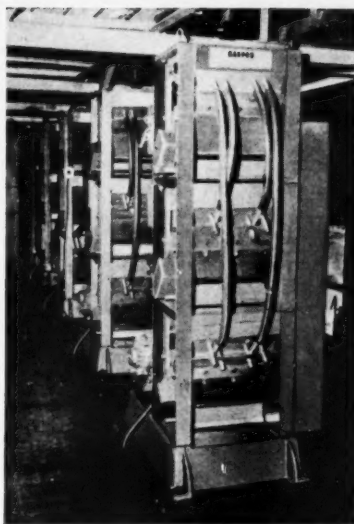

Fig. 2. Five 3-rotor induced roll magnetic separators removing staurolite from tailings of ilmenite mill. Capacity is 3 tons/hr./separator.

and reduces the power required to drive the machine. The highest possible flux, used for separating minerals which are very weakly magnetic, is obtained by making the smallest air-gap which will allow the particles of mineral to pass through. Simultaneously, a low rotor speed is employed, so that centrifugal forces acting on the material being thrown off the rotor are overcome by magnetic forces acting in the rotor.

Where the magnetic machines are applied to the handling of a variety of different minerals, a variable speed drive permits a wide range of rotor speeds to suit specific minerals. Rotor speeds are usually best determined by experiment with a given mineral. It should, however, be kept in mind that centrifugal force which increases with rotor speed tends to throw the material at a higher trajectory from the rotor; while at the same time magnetic forces present tend to lower the trajectory of the material as it leaves the rotor. The highest centrifugal force obtainable to throw the material off the rotor, combined with the highest magnetic force obtainable to lower the trajectory as it leaves the rotor, results in optimum separation. Since the amount of power required to turn the rotor and the amount of heat generated by the rotor is increased as rotor speed increases, or the amount of magnetic flux increases, it is desirable to use the least flux possible to obtain a clean separation and the lowest rotor speed possible which will still throw all the non-magnetic minerals off the roll.

In most instances, materials easily separated magnetically are treated at high rotor speeds and with a wide air-gap. Those that are very weakly magnetic, or difficult to separate magnetically, are best separated with slow rotor speeds at very narrow air-gaps.

Considering the large amount of minerals which they are capable of handling within a short time, the power requirements of modern magnetic separators are not high. Each single rotor unit has two coils connected in series which require about 3.5 amps. at 110 v., d.c. The d.c. switches used absorb the inductive kick-back current which arises when the switch is opened, thereby allowing the magnetic field surrounding the coils to collapse without doing any electrical damage. Under normal operating conditions, each single rotor requires one h.p. to operate on most types of minerals; but where wide gap spacings are used for highly magnetic minerals, no strong field of magnetic force is acting on the rotor, and consequently less power is required to drive the rotor.

High-tension separation

The earliest mineral separation processes using high voltage were of an almost truly electrostatic nature, employing charged fields with little or no current flow. This idea is still widely used in electrostatic precipitators. High-tension separation, on the other hand, makes use of a very high rate of electrical discharge, and electron flow and gaseous ionisation play a major part. The attraction of particles of one charge towards an electrode having an opposite charge is referred to as the 'lifting effect' (Fig. 3; 1a). This effect may be put to use in industrial practice for the separation of minerals which can become either negatively or positively charged. Such a definite polarity can effect the separation even when the conductivity of the mixed minerals fed to the grounded rotor is similar. When compared with the older method of electrostatic separation which is easily brought to a standstill by changes in moisture content or temperature of the minerals, modern methods which are largely immune to these factors represent a definite advance.

By changing the type of electrode from one of large diameter to a number of fine wires, one obtains the 'pinning effect' (Fig. 3; 1b). The action of the fine wire electrode is to give a spray discharge of electricity which builds up a high surface charge on mineral particles of poor conductivity, and this charge attaches them, or 'pins' them

to the rotor surface; those particles not so charged being thrown off the rotor at a normal trajectory, for these have a high conductivity and so remain unaffected by the spray discharge. The electrode polarity has less effect in the pinning method than in the lifting effect, because the charge assumed by the minerals is opposite to that of the rotor. In mineral separation plants both the lifting and pinning effects are put to use, and where the discharge from the electrodes is sufficiently high it is possible to separate certain minerals at high feed rates in one pass (Fig. 4).
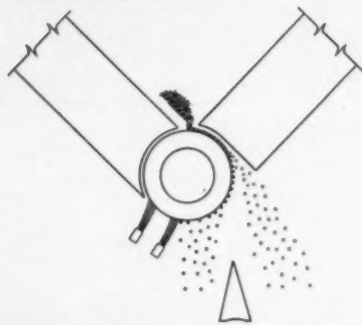
Fig. 4. Materials are split into two fractions as a result of the high-tension field.

Beam-type electrode

The use of a beam-type electrode (Fig. 3; 1c), yields a very dense high voltage discharge, and this electrode is really a combination of two electrodes, consisting of a large-diameter electrode and a fine 10-mil wire placed longitudinally on it and making good electrical contact with it. When in operation, the thick electrode tends to have a non-discharging field which is short and dense, while the 10-mil wire tends to discharge readily. The effect of this is to create a discharge that can be ' beamed ' in a required direction, and in the form of a narrow arc to give a strong pinning effect. This type of discharge gives a large amount of gaseous ions because of the high voltage gradient in the field of the corona. By rotating the electrode enough to permit the effects of both the small and large diameter electrodes to reach the minerals, a combined lifting and pinning effect can be created. With the electrodes so positioned, the mineral particles of low conductivity receive a pinning effect from the 10-mil wire, while the particles of high conductivity receive a lifting effect from the large-diameter electrode (Fig. 3; 1d).
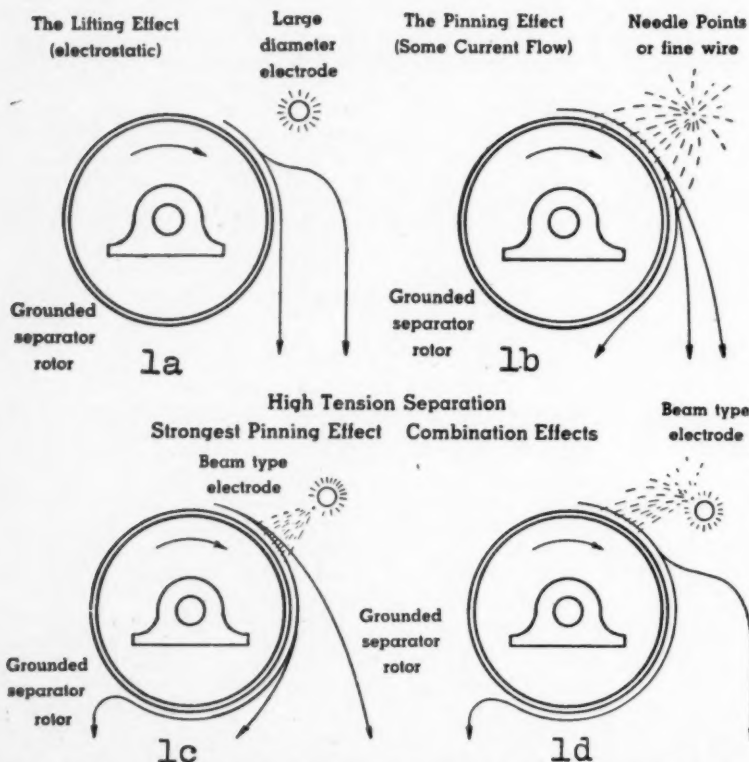
Most high-tension separators now fabricated are designed to make use of the strongest pinning effects, accomplished by using beam-type electrodes, and for certain minerals, positioning these electrodes to obtain combined lifting and pinning effects. Summing up these four methods of separating minerals by high tension, the first one is the electrostatic method and has been in use for over half a century. It operates on voltages up to 20,000, while the current flow per 5 ft. of separator rotor is up to 20 microamps. The degree of separation in one pass does not often exceed 20%, and is much less with unfavourable particle sizes, moisture contents and temperatures. The second system, a normal pinning effect, is not very sensitive to moisture and temperature, and can produce a separation as high as 90% in one pass. It uses voltages up to 30,000 and the current flow per 5 ft. of separator rotor is up to 1,000 microamps. The third technique, beam-type discharge, gives a separation up to 98% in one pass, and it is not very sensitive to the condition of the mineral particles. Its voltage range is up to 50,000, while the respective current flow is up to 2.5 milliamps. The fourth method, combination effects, also gives about 98% separation in a single pass. Operating on voltages up to 30,000, its current flow is up to 1 milliamp. From these data it is readily seen that the old electrostatic separators are extremely inefficient both as regards the minerals which they can handle, as well as the low output per pass.

The beam-type electrodes used are commonly made of tungsten, chosen because of its high tensile strength; but any other metal may be used, with an accompanying shorter life. The required high voltage is connected from a rectifier to the high tension separator through an insulated lead, while a flexible lead carries the high voltage to the beam electrode. By the use of a lever, the distance of the electrode from the rotor can be altered while the machine is in motion, and thus the operating conditions changed. Most separations can be made with rotor speeds of between 200 and 600 r.p.m., but electrostatic separations are generally carried out with rotor speeds of under 50 r.p.m.

Minerals which have been pinned to the rotor are removed by the use of a wiper system and dropped into a separate container. This material is the non-conducting portion of the minerals. The pinned material adheres to the rotor because of the

The Lifting Effect (electrostatic) Large diameter electrode
Grounded separator rotor 1a

The Pinning Effect (Some Current Flow) Needle Points or fine wire
Grounded separator rotor 1b

High Tension Separation

Strongest Pinning Effect Beam type electrode
Grounded separator rotor 1c

Combination Effects Beam type electrode
Grounded separator rotor 1d

Fig. 3. Diagrams showing the effect of various types of electrode operating with a grounded or earthed separator rotor.

Fig. 5. Group of high-tension separators with three feed elevators in the foreground.

charge received from the large d.c. beam electrode, and it is necessary constantly to remove this material so that the rotor presents a clean surface to the incoming minerals. On small-capacity rotors, where the charge is not of considerable magnitude, the pinned material is constantly removed by a dry felt wiper held tightly against the rotor by a spring. For large industrial rotors, however, the felt wiper would normally be inadequate. Therefore an additional electrode is employed which electrically removes the pinned material by neutralising the charge with a.c. This a.c. system comprises a transformer and one electrode to each rotor, the electrode being fitted underneath the rotor and held in position by thumb screws. The distance between this electrode and rotor can be varied to suit different degrees of pinning.

At a typical American minerals recovery plant in Florida the daily output is about 700 tons of unseparated minerals, from which about 300 tons of titanium minerals are recovered; both by high-tension and magnetic separation. Titanium minerals are separated from the less valuable silicates by high-tension rotors, 62 of which are arranged in groups for roughing, scavenging and final cleaning (Fig. 5). This mineral mixture is ideally suited to the high-tension process of separation, for the titanium compounds are conductors, while the silicates are non-conductors; the former are, therefore, thrown off the rotors and the silicates are pinned. In the preliminary or roughing stage where the mineral mixture is at an

Estimation of Prandtl Numbers

By Prof. D. S. Davis*

Where experimental values of thermal conductivity, viscosity, and specific heat are lacking, the Prandtl numbers for many liquids can be estimated by means of Denbigh's equation[1]:

$$\log Pr = \frac{100\ \Delta H}{T} - 1.8$$

where Pr = Prandtl number
T = Temperature, °K.
and ΔH = Molal latent heat of vaporisation, kg. cal.

This equation can be solved readily and accurately through use of the accompanying nomogram. The broken

index line shows that the Prandtl number of bromobenzene (molal latent heat of vaporisation = 8.966 kg. cal.) is 14 when the temperature is 32°C. or 305°K.

REFERENCE
[1] R. C. Reid and T. K. Sherwood, ' The Properties of Gases and Liquids,' p. 261. McGraw-Hill, 1958.

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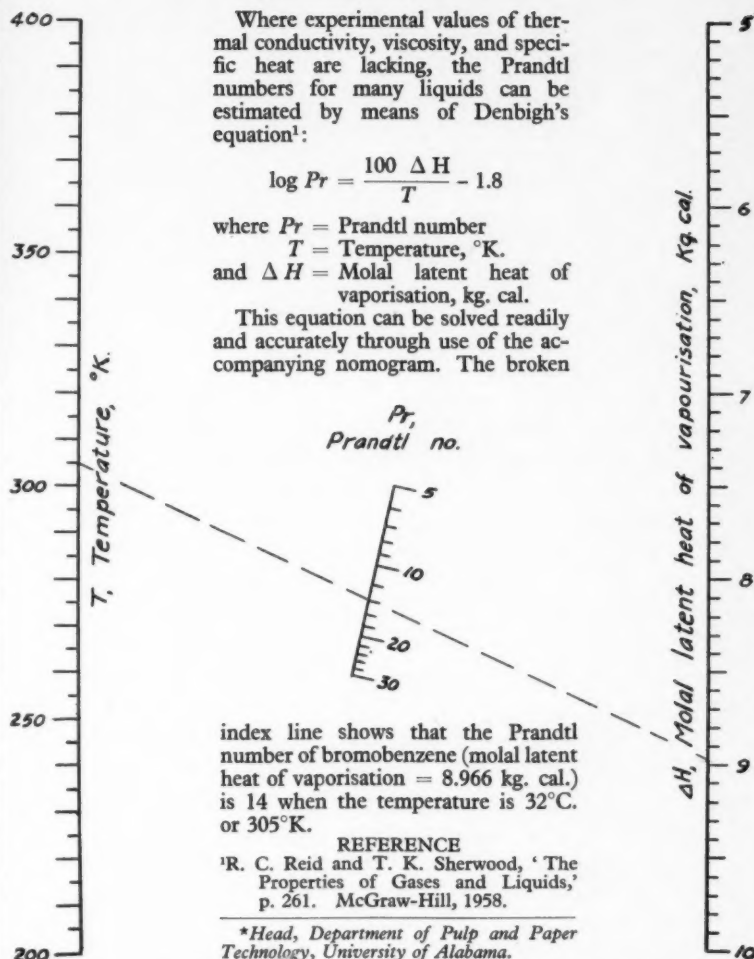
elevated temperature through being dried in oil-fired kilns, the silicates are pinned so strongly that the wiper electrode, carrying high-voltage a.c., has to be continuously in operation to keep the rotor clear. The recovered silicates are passed to magnetic separators to yield a magnetic fraction which is largely staurolite containing traces of tourmaline. This fraction contains more than 45% alumina and is used by Florida cement plants as a source of alumina in cement-making. Titanium minerals which have been flung off the rotors are likewise passed to magnetic separators to produce ilmenite containing about 63% titanium oxide, and a non-magnetic fraction which is chiefly leucoxene. The latter mineral, after two-stage high-tension cleaning, contains about 80% titanium oxide.

Titanium minerals which have been finally concentrated by these electrical separators contain only about 1% of silicates, and they are shipped to a plant of E. I. du Pont de Nemours for the production of titanium metal and pigments.

In these mineral separating processes a complete separation can rarely be achieved in one passage of the material through the machines, no matter how efficient the latter may be. There is always a certain proportion of entrapped particles. Thus, material which should be thrown off the rotor becomes entrained with pinned particles, and those which should be pinned become entangled with particles being thrown off. Several passes are, therefore, usually necessary to obtain a mineral of very high purity.

Materials of Construction

for
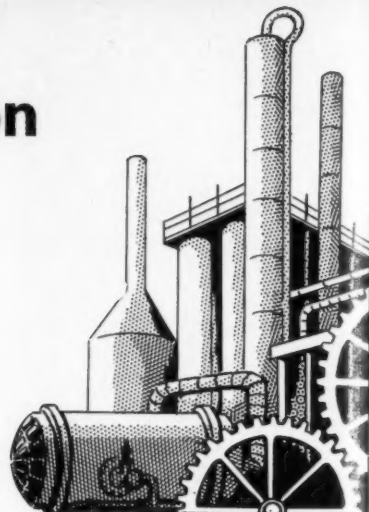
Chemical Plant

Starting with next month's issue we shall publish a comprehensive series of articles dealing with materials of construction for chemical plant. The purpose of this series will be to discuss critically and evaluate the suitability of most metals and non-metals for use in modern chemical plant. One article will appear each month, devoted to the following: mild steel, stainless steel, titanium, copper-bronze, lead, nickel, aluminium, rare metals, graphite, timber, ceramics, glass, rubber, PVC, polyethylene and reinforced plastics.

Well-known experts have contributed these articles and, in order to achieve uniformity, they were asked to write their articles according to these three terms of reference:

(1) To describe the physical structure of the material and mention the technological procedure involved in manufacture as well as the alloys or polymeric blends that can be obtained. To deal comprehensively with corrosion and ageing resistance.

(2) To give an historical review of the uses of this material in chemical plant construction, laying particular emphasis on its contemporary utilisation. For the purposes of this series nuclear plant will be considered as chemical plant.

(3) To assess critically the intrinsic value of the material to the plant designer, taking into account future trends in the chemical industry.

It is earnestly hoped that this series will lead the way towards a more complete appreciation of both conventional as well as modern materials at the disposal of the chemical industry.

To introduce this series we present on the following pages three articles which deal with the general problem of materials selection from various aspects.
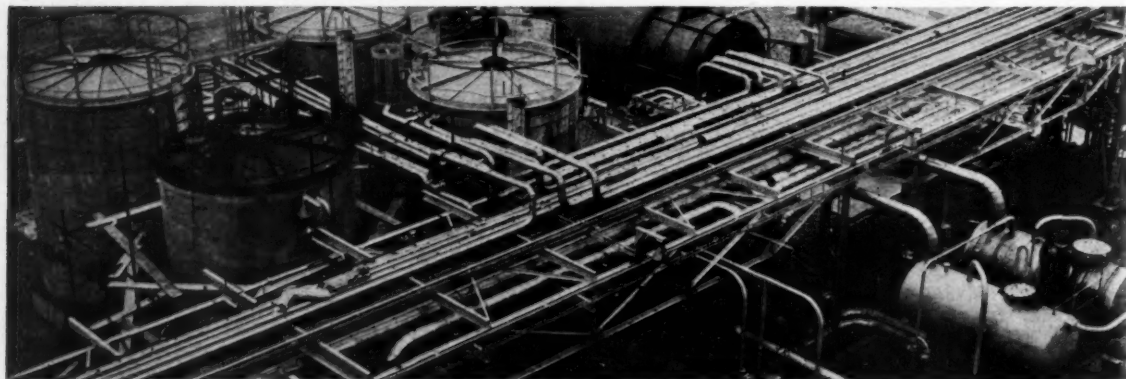
A view of the oil heating furnace and tanks for the storage of epichlorhydrin at the Shell Chemical Co. Ltd., Stanlow.

1—Some General Considerations

By S. C. M. Salter,* B.Sc.(Tech.), A.M.C.T.

THIS article is a preliminary to a series of articles on particular classes of materials of construction for chemical plant. Hence it is proposed to deal here with some general considerations affecting the usage of materials as a whole.

Choice of materials is an important consideration in all branches of engineering. In chemical engineering, however, the problem is most complex due to the problem of overcoming corrosion by a much wider range of media than in other fields. If modern processes are to be carried out reliably and economically a wide range of materials has to be employed.

In the early days of the chemical industry the application of many scientific discoveries on an industrial scale was frequently hampered, if not entirely prevented, due to lack of suitable materials. Few metals were available in quantity; cast iron was of poor quality; there was little wrought iron or steel. The non-ferrous metals available were lead, copper, brass and gun-metal, but were expensive. In addition, methods of fabrication were primitive, for example, welding, except for forge welding, being unknown. Since those early days the advances in metallurgy have been immense. These advances were often stimulated by an obvious engineering need and the resulting new material then led the plant constructors to raise their sights and call for further advances to permit the proper development of their designs.

Modern materials

Today it is difficult to imagine ourselves without aluminium, nickel and its alloys and stainless steel, although their development as materials of construction for chemical plant has all taken place over the last 40 years. In more recent years metals such as tantalum, titanium and zirconium have been developed from laboratory curiosities to practicable materials of construction. Now we have in use ferrous alloys including stainless steel; copper and its alloys; aluminium and its alloys; nickel and its alloys; lead, zinc and tin; titanium, tantalum and zirconium; and the precious metals. In each of these various categories

*British Chemical Plant Manufacturers' Association.

there is a whole family of alloys, additions to which are constantly being made. To this must be added the non-metallic materials—stoneware, glass, carbon and graphite, rubber and ebonite, and the ever-increasing family of plastics. Instead of a crippling shortage the designer of the less-exacting type of plant is now faced with almost an *embarras de richesses*. The following articles will no doubt provide many useful guides to selection of the right material for the intended plant.

Lack of central reference

There is, however, no central source of information on materials of construction as a whole. Various efforts in this direction have been made from time to time in the form of charts of corrosion resistance by technical journals and others. The permutations of materials of construction and operating conditions are, however, now so vast as to require a considerably more extensive treatment than has so far been attempted. Furthermore, new alloys and new operating data are continually becoming available, so that any compilation would need to be kept under constant review. What body might be responsible is an open question but it might well be worth the consideration of D.S.I.R. It is not suggested that any such central reference would or should give all the answers, but it could save all parties considerable waste of time by quickly providing a short list of materials ' in the running.' Final selection should be made only after consultation with the material suppliers.

Collaboration

Consultation between user, plant-maker and material supplier is a point which cannot be too strongly stressed in the chemical and process industries. As has already been mentioned, the combinations of materials and corrosive media is vast, but in practice one has also to contend with many complicating factors which at first glance may appear minor, but which in their ultimate effect on behaviour of the plant may be anything but minor. For example, whether a liquid being handled is aerated or not may make a notable difference to corrosion rates. Similarly the presence of small quantities of an impurity may make a notable
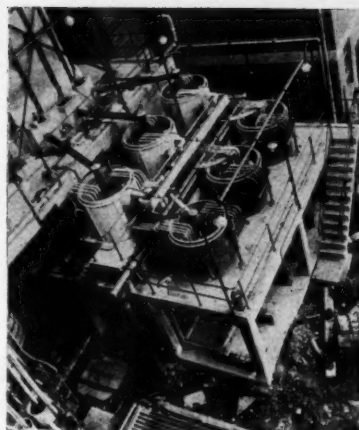
Steel tube supports on lead pot cooler jackets at N.C.B. plant, Chesterfield.
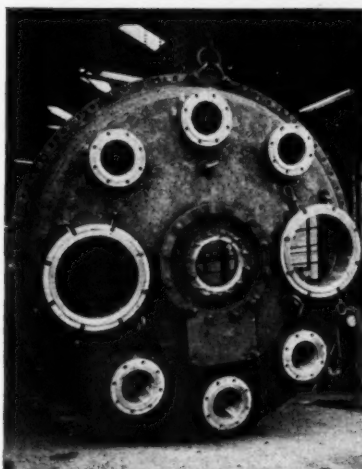
Homogeneously lined 1-in.-thick mild-steel pressure vessel cover.
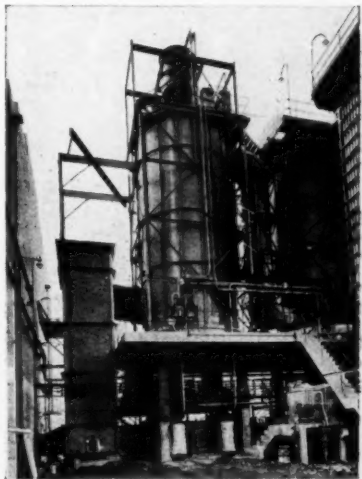
Concentration tower at N.C.B., Chesterfield: ⅜-in.-thick suspended sheath erected on site.

difference to behaviour. Design of the plant itself may produce complications as, for example, electrolytic effects due to the juxtaposition of different alloys or concentration cells due to stagnant pockets and crevices.

These considerations may appear obvious to many but are certainly not universally borne in mind, as evidenced by the following examples of comparatively recent occurrences.

(i) In a process for treating paper, sulphuric acid was used. The customer gave what seemed to be a careful and explicit statement of his working conditions and it was suggested that he should consider using *Monel*. Items of *Monel* were incorporated in his plant and failure occurred within a few days. The customer had made no mention of the fact that he found it advantageous to introduce small quantities of nitric acid into the process.

(ii) Failure of plant in 18/8/3 stainless steel handling dilute sulphuric acid occurred, due to the undisclosed presence in the acid of organic sulphur compounds. The passivity of the stainless steel was reduced with consequent failure.

(iii) Failure of an aluminium alloy handling acetic acid occurred because the acid contained appreciable quantities of copper. The significance of this was not appreciated by the customer and was not mentioned by him.

These random examples related to firms of importance in the industry. The total number of unfortunate occurrences particularly in the smaller firms without staff with adequate scientific outlook is probably considerable. It is obviously of advantage to all that there should be absolute frankness regarding details of the plant and process when materials of construction are being discussed with the possible suppliers. The chemical manufacturer may not wish to divulge all the details of his process. This is understandable, but he should realise that he may thereby be running the risk of premature plant failure which cannot be laid at the door of his material or plant supplier.

The above remarks give the negative side of collaboration, namely prevention of failure. The positive side, the promotion of better materials or better use of materials, is of potentially greater value. The proof of the pudding is in the eating or the proof of a material is its actual behaviour on the plant. The more the users can provide, or give facilities for obtaining plant corrosion data the better placed will be the materials suppliers for evaluating the potentialities or shortcomings of their materials and so for providing a more reliable service for the future needs of the users.

Laboratory corrosion tests are of value in establishing whether a material is worthy of consideration for plant handling a given chemical. The only real check is on the actual plant. This, however, involves risk and certainly a considerable length of time. A very useful halfway stage is the incorporation of test specimens in an operating plant. It gives results but one stage removed from actual practice and has the advantage that a number of variants can be tested comparatively cheaply within a reasonable period. An extension of collaboration on tests of this nature would thus be of great mutual benefit.

It is probably fair to say that today there are few instances where building of plant is positively precluded by lack of a material of construction. On the other hand, it is still true to say that in many cases a better plant technically and economically could be designed were more suitable materials available or the potentialities of existing materials better known and utilised.

Over-design

The general trend is towards increasing stringency of demands on materials. Many new processes, particularly in the field of petrochemicals, call for the use of high temperatures coupled in some cases with high pressures. There is also a tendency for such processes to be on a large scale to make their exploitation worth while. This, in turn, means large vessels and an increasing demand for materials of high tensile strength or yield point at elevated temperatures coupled with a low creep rate to allow for reasonable design. Here, in addition to scope for new improved alloys, there is a need for the establishment of reliable, agreed figures for mechanical properties. For example, work on the preparation of that monumental standard B.S. 1500, ' Fusion welded pressure vessels for the chemical, petroleum and allied industries,' is affected by the problem. Uncertainty leads to the use of stress figures which, in actual fact, may well be too low or to the adoption of factors of safety which may be too high. This, in turn, leads to over-design, an uneconomic price and possible loss of an export order to other countries where they have more reliable figures, a more optimistic approach or more accommodating insurance companies.

Up to about 650°F. factors of safety in this country generally vary from 4 to 5 whilst in America they would appear to vary from 3 to 4 and in some continental countries might be as low as 2 to 3. In certain cases, therefore, the British designer may be using nearly twice as much steel as his continental rivals for a similar job. British practice rightly stresses the need for safety, but a factor of 5 on the ultimate tensile at atmospheric temperature is really a factor of safety coupled with a factor of ignorance. With increasing knowledge of resistance of metal to plastic deformation at service temperature and of stress concentrations at openings or connections the old conservative figure might be substantially increased provided there remained a reasonable

Pavior floor and channels jointed in phenolic type resinous cement.
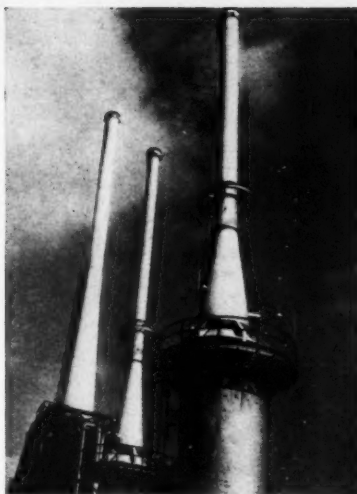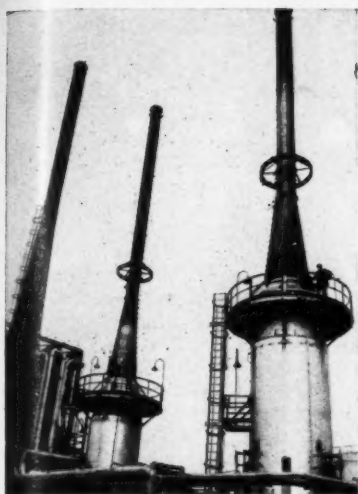
Chimney stacks at Esso Oil Refinery, Fawley: *left*, before aluminium spraying; *right*, after spraying.

margin above the yield stress at the service temperatures. It is encouraging to note that a British Standards Institution Committee is at present studying the question of higher design stresses to be used under approved conditions in connection with B.S. 1500.

Much work has been done on creep of special heat-resisting alloys at the high temperatures experienced in gas turbines, but it could well be that further work on the less exotic alloys at the more modest temperatures used in the chemical industry would be useful to determine at what point creep becomes a significant factor in design. Such work should embrace the aluminium alloys as well as steels.

The introduction of tonnage oxygen plants, distillation of hydrogen, separation of gases and the transport and storage of liquid hydrocarbons are creating a need for increased quantities of metals suitable for operation at sub-zero temperatures. A major problem here was the tendency of many materials to cold brittleness. Aluminium and certain nickel and austenitic 18/8 stainless steels are available which are free from this defect. It would be helpful to designers, however, if fuller information on low temperature properties of a wider range of materials were made known.

Economic factors

A general tendency is towards operating units of increased capacity and, wherever possible, to convert former batch processes to continuous automatic operation. This has the advantages of more economical opera-

tion and greater consistency of product, but the disadvantage that a breakdown at any one point is likely to mean disruption of the whole processing line with consequent substantial loss. To avoid this possibility complete reliability of materials of construction is essential. This applies particularly to items of smaller equipment such as valves and pumps. The temptation to take a chance with a relatively cheap but not quite so good material may be strong, since a replacement would not cost so very much. This may be true of the direct cost of replacement, but the indirect cost in loss of production is likely to be quite a different matter. Indeed, it is probably in the smaller items of plant where it is most worth while to indulge in the more exotic materials, in valve seats and pump impellers, for example, which are subjected not only to corrosive attack but also to abrasion and erosion.

In addition to increased reliability of operation of plant there is also an increasing trend towards improved purity of product. Thus in many plants corrosion is to be avoided, not only to the degree necessary to give a reasonable life to the plant but to an even higher degree to avoid any contamination of the products handled. This means that suitable corrosion-resistant materials must be used for all surfaces in contact with the product. In a large plant this may mean a considerable expense. For large vessels, however, linings of protective materials or clad steels can often provide a helpful solution. Relatively cheap mild steel carries the bulk of the stress, whilst the more expensive material is present only in sufficient

thickness to meet the corrosive conditions. Steels clad with a variety of materials, such as *Monel*, stainless steel and titanium, are now available, and with increasing experience of their fabrication are likely to be in increasing demand.

Rationalisation

In view of the wide range of operating conditions to be met one might well echo in connection with materials the famous phrase of Mao Tse Tung, ' Let a thousand flowers blossom.' It appears that Mao's object was only to lure the flowers into showing themselves so that he could more easily eliminate those which diverged from the approved party line. We should certainly not follow his example except in so far as it would be a useful exercise to classify more sensibly our thousand blossoms to see which are really useful variants.

In certain classes of materials, notably the carbon and stainless steels, there has been an undue multiplication of specifications varying only in a minor degree from one another. This has doubtless arisen from the efforts of the suppliers to meet the unco-ordinated needs, real or imaginary, of separate sections of industry and of individual firms and also from individual suppliers' particular production procedures.

At a symposium on stainless-steel specifications held in 1952 by the Institution of Chemical Engineers it was learned that probably the country's largest user of stainless steel bought to his own specifications which were not covered at all by B.S. 1501-6, while

Circular expansion joint, constructed from rubber-impregnated canvas covered with abrasion-resistant rubber.

2 — General Classification of Materials

By E. W. Jackson, A.M.C.T., A.M.I.Chem.E.
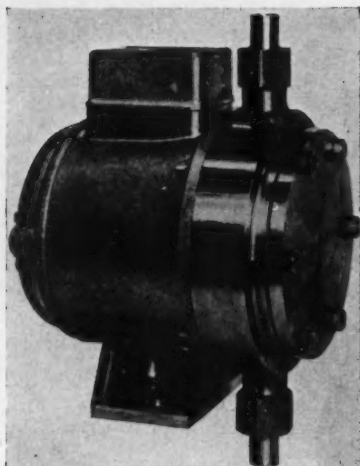
Totally-enclosed glandless pump made of stainless steel.

others always bought by brand names. Stainless steel produced by different manufacturers to the same nominal composition show marginal differences in both fabricating properties and corrosion resistance. Also, the situation between American and British specifications needs some rationalisation. The plant industry meets this problem, as it is often called upon to work to U.S. specifications. It is encouraging to note that the B.S.I. is now devoting more attention to this question of rationalisation of specifications.

Rationalisation is of importance if we are to produce and use our materials most economically. This does not mean that the production of 'specials' should be frowned upon. On the contrary, the ability of material suppliers to provide such specials is a development of which we should take full advantage where the specification to be met is indeed special.

The vigorous growth of the chemical industry since the war has been accompanied by a similar vigorous growth of its supporting plant industry. After some recent hesitation the outlook for new plant developments again looks promising. Furthermore, the plant industry now has a sufficient store of design and manufacturing ability to be able to supply increasing quantities of plant to the many overseas countries anxious to develop their own chemical and process industries. All this will be reflected in the demand for materials of all types with the brightest prospects for those higher-grade materials capable of standing up to the increasingly stringent requirements of modern processing techniques.

MATERIALS of construction may be classified into metals and non-metals, and these groups may be further sub-divided:

Metals	Non-metals
Metals of commercial or chemical purity Alloys	Ceramics Plastics Elastomers Glass Graphite Refractories Cement and concrete Timber

The following are the chief metals, alloys and plastics encountered as materials of construction in chemical engineering.

Metals	Alloys	Plastics
Aluminium Copper Iron, including mild steel and cast iron Lead Nickel Silver Tantalum Titanium Zirconium	Aluminium-copper Copper-tin (bronze) Copper-zinc (brass) Iron-chromium Iron-chromium nickel (stainless steel) Iron-silicon (high silicon iron) Lead-antimony and lead-tellurium Nickel-copper Nickel-chromium-molybdenum-iron	Epoxy resins Nylon PCTFE (polychlorotrifluoroethylene) Polypropylene PTFE (polytetrafluoroethylene) Polyethylene PVC (polyvinyl chloride)

The use of satisfactory materials of construction in a chemical engineering project is extremely important, as the success of the project may depend on their correct selection. There are many things to study when choosing a material of construction, but factors which must be considered are the following:

1. Purity of the product being manufactured.
2. Physical properties of the material of construction.
3. Ease of fabrication.
4. Economics.

Purity of the product

Purity of the product is not always related to the rate of corrosion of the plant.

If the corrosion product is insoluble and is separated from the final product, corrosion rates may not be important under this heading. Sometimes a small amount of corrosion

product may combine with the material being manufactured to give an undesirable colour in the final article, and the use of materials of construction having colourless corrosion products is indicated.

In certain industries—food and pharmaceuticals—it is important to see that toxic corrosion products do not accumulate in the articles being manufactured. Plant for biochemical processes must be constructed of materials that do not yield corrosion products which are toxic to living organisms. A further point to bear in mind is the catalytic effect of some materials of construction, which may lead to the decomposition of the materials being handled, or may render chemicals, which are otherwise harmless, potentially explosive.

The physical properties of materials of construction which are most important in chemical engineering are: tensile strength, hardness, fatigue compressive strength and impact strength. Frequently metals show a greater resistance to corrosion the greater their purity. However, the increase in purity often has an adverse effect on the physical properties. Certain metals are comparatively expensive when highly purified, and if these materials are used the cost is increased further because greater sections must be employed to compensate for loss in such physical properties as tensile strength. A method of utilising the corrosion resistance of materials of construction which have poor physical properties is to use them as coatings or linings on cheaper and stronger materials.

Fabricating metal plant

One of the most important methods of fabricating metal plant in chemical engineering is by welding, and metals which cannot be fabricated in this way have limited application. The reason for this is that other methods of joining pieces together either introduce other metals or introduce crevices, both of which are undesirable under corrosive conditions.

Some materials cannot be machined; this means that they must be shaped by casting, and any final finish must be achieved by grinding. Other metals or alloys, whilst offering excellent corrosion resistance, work harden. Consideration must be given to all these limitations during the design of equipment.

Economics

Rarely can a material of construction be selected by considering economics alone. The economics in the use of a particular material is related to the corrosion rate; where there is no damage to the manufactured article, it may be more economical to accept a relatively high corrosion rate, than to use a material with greater corrosion resistance. This point must be considered at the design stage, but one of the difficulties in carrying out an economic study at this stage is in obtaining reliable data on rates of corrosion.

The selection of suitable materials of construction for chemical and process plant is part of the training of a chemical engineer; it is a subject in which a little knowledge is a dangerous thing. Corrosion charts are available which indicate the suitability of materials of construction for use in contact with a range of chemicals but these charts can be misleading to anyone not trained in this field. It is not sufficient to know that a material will resist corrosion in a particular environment. To be competent to select a material of construction one must know why it is resistant to corrosion.

A series of articles on materials of construction is to be published commencing with the next issue of CHEMICAL AND PROCESS ENGINEERING. With the exception of certain alloys that are more conveniently dealt with under the metal which is their main constituent, an article will be devoted to each material. It is hoped that this series will demonstrate the unifying approach to this subject and assist both chemical engineers and technical staff without a chemical engineering training to select their materials of construction with confidence.

3—Plastics in Chemical Plant

By J. A. Rhys,* M.Sc., A.K.C.

ALTHOUGH three groups of plastic materials, PVC, polyolefines and reinforced plastics, will each be fully discussed in this series, it should be of interest in the introduction to discuss the overall contribution of plastics to the chemical construction field.

Naturally the chemical engineer has to apply the same rigorous tests and judgments to a newly developed plastic as to the oldest established metal. This is not always to the detriment of the newcomer, as the suitability and usefulness of the more conventional materials are often re-examined in the light of this new evidence.

ledge of these materials by the user industries, and to the absence of exact data on their properties, in particular on the changes in these properties which take place on long-term ageing. Some having only been in commercial production for a few years, this is not surprising. Many manufacturers have provided data, and have extrapolated these data to forecast properties up to 20 years. Two such forecasts are illustrated in Figs. 1 and 2. Both are related to the burst strength of piping. The A.B.S. polymer in Fig. 1 is a blend of resins and rubber containing acrylonitrile, butadiene and styrene.[1] The polyethylenes in Fig. 2 are repre-
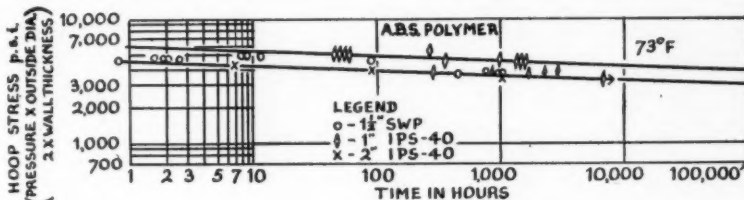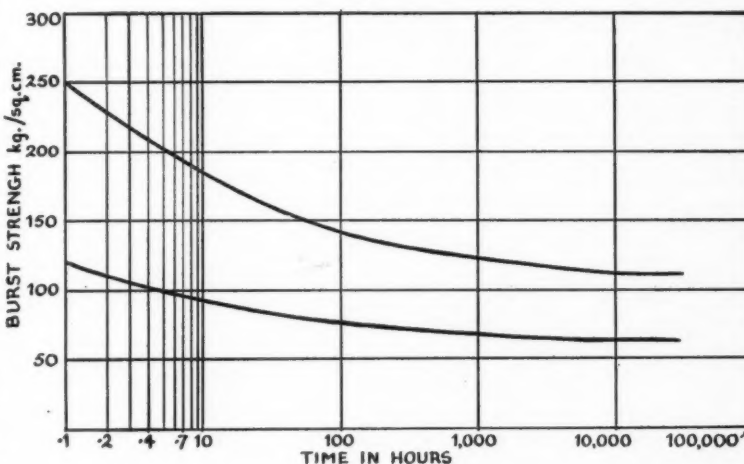

Fig. 1.

Fig. 2.

A number of plastic materials combine resistance to corrosion and abrasion, high mechanical strength, lightness of weight, ease of fabrication and resistance to chemical attack. Materials with these combinations of properties are valuable for many applications in the chemical industry; however, their use, though growing rapidly, is relatively small. To a large extent this is due to a lack of know-

sentative of the materials produced by high-pressure and low-pressure polymerisation.[2] With these limitations in mind the main applications as constructional materials have been in the following fields: piping, reaction vessels, storage tanks, gas washing towers, duct work, ventilating systems, organic linings, mortars and cements.

*F. W. Berk & Co. Ltd.

Properties

Table 1 lists the important physical properties of the plastic materials which could be used in these fields. The values shown are representative averages. They may vary considerably in any group, depending on the specific resin used and the method of fabrication. Thus with each material there may be special grades with properties markedly different from the average properties. This is illustrated in Table 3 which gives the properties of the various grades of I.C.I. nylon.[3] Here can be seen the considerable differences which can be encountered in one material. With polyethylene (Table 4) it is perhaps most instructive to compare the low- and high-density polyethylenes.[4]

It should also be noted that the values given in Table 1 are those which would be obtained at room temperature, and that great changes in these values occur with only a small change in temperature. The results obtained when determining a mechanical property of a given sample of a plastics material will depend on: (1) the past history of the test piece and (2) the way in which the test was carried out, especially (a) the rate of loading and (b) the temperature at which the test was performed.

These effects are best illustrated by reference to published work on various plastics materials.

By the previous history of the sample it is implied that consideration should be given to the method by which it was produced, as well as to whether it had received any adventitious deformations before it was tested. In many tests it is possible to

'Neoprene' rubber coating applied to the roof of a pickling shop.

condition the sample and so to minimise the effects of past history. Some effects, however, cannot be wiped out. Mouldings of rigid PVC shrink approximately 0.015 in./in. in the line of flow, and only 0.006 in./in. at right-angles to this line of flow. As a result, different strains are set up in the moulding depending on the position and size of the gate. For the Izod method for measuring impact strength a moulded bar of $\frac{1}{2}$ in. sq. cross-section, with a centrally positioned notch is used. The results obtained by Whitefield showed wide differences with different locations of the gate.[5] Similar results have been reported by Hogberg.[6] Vincent[7] has commented on the notch-sensitivity of certain plastic materials. This notch may be external,

either deliberately or accidentally caused, or internal, caused by voids, spherulites or other inhomogeneity. The notch creates a stress concentration which can be considerable and, by altering the stress state of the sample, makes it more susceptible to brittle fracture.

Effect of temperature

The next factor is temperature. Many of the properties of a thermoplastic material alter rapidly with temperature. A piece of PVC may be hard and brittle at room temperature, and soft and rubbery at 100°C. The range of temperature over which the properties change from one extreme to another is not large. Thus it is important that tests should be made at

Table I. Properties of plastics materials

Properties		Rigid PVC	High-impact rigid PVC	Poly-ethylene, low-density	Poly-ethylene, high-density	Styrene co-poly-mer-rubber	Styrene co-poly-mer	Cellulose acetate butyrate	Poly-methyl metha-crylate	Nylon-66	Poly-ester glass-fibre
Specific gravity	.. ..	1.4	1.35	0.92	0.95	1.05	1.05	1.2	1.19	1.14	1.7
Tensile strength, p.s.i.	..	8,500	6,000	2,500	4,000	5,000	3,000	5,500	9,000	11,000	20,000
Flexural strength, p.s.i.	..	14,000	10,000	1,800	1,400	8,500	6,000	6,000	16,000	12,000	40,000
Izod impact strength, ft.lb./in. of notch		1	16	30	3	8	2	2	0.4	3	15
Heat distortion temperature at 264 p.s.i. fibre strength	°C.	75	70	50*	60*	86	86	80	105	75	—†
	°F.	167	158	122	140	186	186	176	222	167	—
Maximum useful service temperature, °F.		160	150	125	160	170	170	140	80	210	275
Thermal expansion, in./in. °F. × 10⁻⁶		4	6	10	11	5	5	7	9	10	1

*Tested at 66 p.s.i. fibre strength † Thermoset

Table 2. Chemical resistance of plastics materials

	Rigid PVC	High-impact PVC	Poly-ethylene low-density	Poly-ethylene high-density	Styrene co-poly-mer-rubber	Styrene co-poly-mer	Cellulose acetate burytate	Poly-methyl metha-crylate	Nylon-66	Poly-ester glass-fibre
ACIDS: Hydrochloric, 10% ..	✓	✓	✓	✓	✓	✓		✓	✓	✓
Hydrochloric, 36% ..	✓	✓	✓	✓	✓	✓		✓		✓
Nitric, 10%	✓	✓	✓	✓	✓	✓	✓			
Nitric, 70%	✓									
Sulphuric, 10%	✓	✓	✓	✓		✓	✓	✓	✓	✓
Sulphuric, 95% ..	✓		✓	✓						
ALKALIS: Ammonium hydroxide ..	✓	✓	✓	✓	✓	✓		✓	✓	
Potassium hydroxide ..	✓	✓	✓	✓	✓	✓		✓		
Sodium hydroxide ..	✓	✓	✓	✓	✓	✓				
SOLVENTS: Aliphatic hydrocarbons ..	✓	✓					✓	✓	✓	✓
Aromatic hydrocarbons ..									✓	✓
Chlorinated hydrocarbons									✓	✓
Ketones									✓	
Aldehydes									✓	

√ Resistant and safe for general use

Table 3. Properties of different types of nylon

	A100	B100	B901	LA48	LA38	DA
	66	610	610 66/610/6	66 Plasticised	66/610 Plasticised	66/610/6
Specific gravity	1.14	1.09	1.08	1.16	1.12	1.09
Melting point, °C.	264	220	220	255	184	160
Heat distortion point, °C.	75	55	50	55	40	35
Tensile strength, p.s.i.	11,500	8,500	7,500	7,000	5,000	7,500
Elongation at break, %	80—100	100—150	300	100—120	200—250	300
Young's modulus, p.s.i. × 10^5	4.3	3.0	2.2	1.8	0.5	2.2
Impact strength, ft.lb./½-in. notch ..	1.0—1.5	1.6—2.0		2.0	10	
Hardness, Vickers pyramid	12	11		7	3	
Volume resistivity, ohm-cm.	10^{13}	10^{14}	10^{13}	10^{10}	10^{10}	10^{13}

Table 4. Properties of different grades of polyethylenes

	Density	Grade No.	Vicat softening point, °C.	Tensile strength, p.s.i. 6 in./min.	Tensile strength, p.s.i. 30 in./min.	Elongation at break, % 6 in./min.	Elongation at break, % 30 in./min.	Stiffness modulus, p.s.i.	Environment cracking resistance
Alkathene 2.. ..	0.92	2	91.5	1,690	1,890	500	450	3×10^4	3 hr.
Alkathene 20 ..	0.92	20	83	1,400	1,600	500	450	2.6×10^4	0.25
Alkathene H.D. ..	0.94	0.7	115	2,580	3,030	380	180	5×10^4	1.75
Hostalen	0.95	0.24	118	3,250	3,820	640	60	6×10^4	60
Marlex 50	0.96	0.7	125	4,550	4,900	230	25	9.5×10^4	30
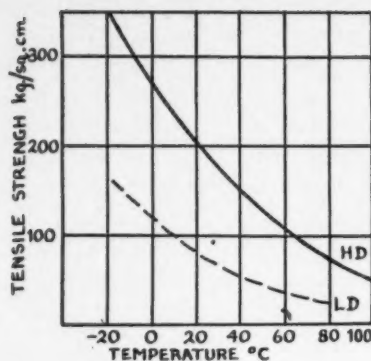
Fig. 3.

specified temperatures, and that the change in properties over the range of temperatures through which the material is to operate should be known. Figs. 3 and 4 illustrate changes in properties of polyethylene[8] with changes in temperature. The densities of the polyethylenes (0.92, 0.94, etc.) are indicated on each curve, and the letters indicate the source of supply. The Vicat needle is a square needle with a 1-mm. side and is under a load of 1 kg.

The final factor which must be carefully controlled is the rate at which the material is deformed or loaded. Thus when deformed rapidly a plastics material appears stiffer than when it is deformed slowly. That these materials are highly sensitive to the rate of straining is shown in Fig. 5.[9]

Thus it will be seen that the information which the chemical engineer requires is not simply a table of values based on arbitrary tests, but information that will give him a full understanding of the behaviour of plastics under stress, and the conditions under which he proposes to use them.

However, due to the paucity of information on the variations of properties on ageing, this means that safety factors of 5 are usually allowed to insure against failure. In addition, since plastic materials are very notch-sensitive, it is common practice to allow safety factors as high as 10 when threaded fittings are involved.

Table 2 illustrates the chemical resistance of the materials considered in Table 1.

Applications

The largest field of applications for plastics at present is in piping. The tables of properties given are the results of short-term tests and cannot reflect such factors as creep under prolonged stress. Actual installations of significance have not been in service long enough to be of any use in pre-

dicting service life. At this stage it would be fair to state that those failures which have occurred can be traced to incorrect appreciation of their properties or to faulty joining technique.

The main feature in favour of plastic piping is its resistance to chemicals and to corrosion. Table 2 indicates that most of the materials show excellent resistance to salt solutions, weak acids and weak bases. As a group they have good resistance to strong acids and bases, but are not recommended for organic solvents.
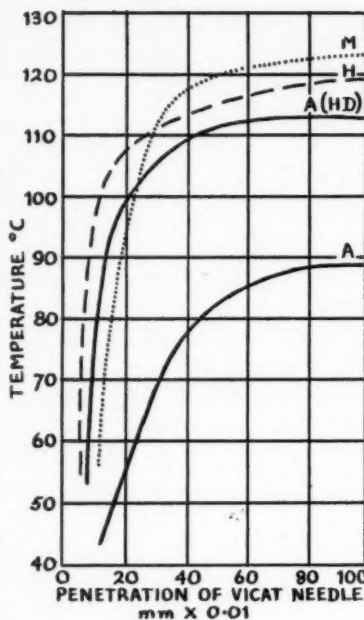
Fig. 4.

Table 1 shows that polyethylene is the lightest material and has the highest impact strength. Polyester glass fabric material is the strongest and has the least thermal expansion. Polyester glass fabric has the highest service temperature, and polyethylene has the lowest.

Polyethylene

Polyethylene pipe represents by far the largest volume of all the plastics pipe in use at present. This is due to its low cost, ease of extrusion, light weight, flexibility, excellent resistance to corrosion and to chemicals, and its ease of laying. Its disadvantages are very low operating pressure and temperature, its flammability, and lack of resistance to hydrocarbons. Its main uses are 'cold water' uses such as cold-water systems, irrigation, drainage pipes, and in food processing plants.

Rigid PVC

Rigid PVC has been used in Europe since 1935 in chemical plants and for water services. In Japan, too, its use is considerable. In the U.S.A. and in the U.K. its growth has been much slower. In both cases this has been due to a very large extent to the prior development of other plastic materials. In the U.S.A. styrene co-polymer pipe was an early development and in the U.K. the potentialities of polyethylene for cold-water applications were recognised and exploited before those of PVC were recognised. Its growth has been limited in many countries by the lack of fittings for the pipe. These are now being produced and, in the opinion of many, this material is considered to have the greatest future of all plastic pipe. This is because of its excellent chemical resistance, high strength, good dimensional stability, wider operating temperature, and ease of jointing and installation. Its main weakness is poor resistance to some organic solvents. This is especially true with the high-impact grade, where this high-impact property has been obtained at the expense of chemical resistance. Its chemical resistance is better than the styrene rubber blends used in the U.S.A.

Jacobson[10] has pointed out that by using the correct plasticiser it is possible to produce a PVC pipe with much the same rigidity as high-density polyethylene, but considerably stronger. He observes that, since the strength of PVC at 20°C. is two to five times that of polyethylene, it is
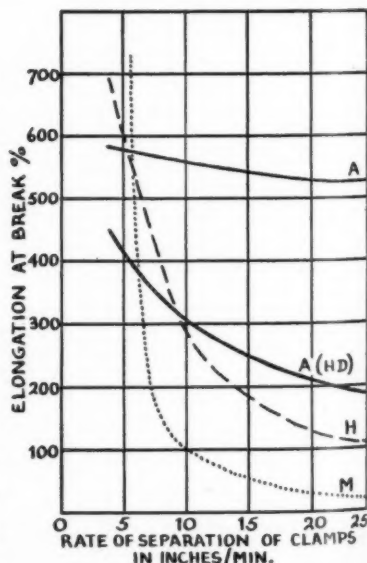

Fig. 5.

possible to make a cold-water tube of semi-rigid PVC much more cheaply by reducing wall thickness. Overall PVC, rigid and semi-rigid, is probably the best of all materials for pipes. The main uses at present are in chemical plant and in piping when strength and shock resistance are required. In the U.S.A. it has been accepted as a standard material for piping for decontamination of naval vessels from radioactive materials.

Styrene co-polymers and rubber blends

Styrene co-polymer and rubber blends have become well established in U.S.A. where they are readily available. They have high impact strength, lightness and toughness. They are easy to mould and to extrude, so that early in their development fittings were available. This above all gave them a good start in the field. Their main limitations are low tensile strength and a chemical resistance not quite equal to PVC. In the chemical field this pipe is in use for dilute sulphuric acid, bleach solutions, both dry and moist chlorine gas, salt solutions, vegetable oils and fatty acids. It has been widely used in water-conditioning systems. In the petroleum industry styrene copolymer-rubber blend pipes have been used for salt water and oil gathering lines, and for the piping of natural gas. A recent study by the National Association of Corrosion Engineers of America made a study of oil-field installations and reported only five failures. Two of these were at solvent-welded joints, and the other three were traced to their use at excessive temperature or pressure.

Cellulose acetate butyrate

Cellulose acetate butyrate is another material which has been developed in the U.S.A. for the handling of salt water and crude oil in the oil-fields, and for the distribution of natural gas. It weathers well, and is easy to install by solvent welding. Disadvantages of this material are low working pressures and temperatures, and poor resistance to acids, alkalis and organic solvents. For these reasons its use has been restricted to the oil-fields, and to natural gas transmission. It could not be recommended for heavy duty, and for chemical plant.

Polymethyl methacrylate piping has not found wide use in chemical plant. It is not attacked by foodstuffs and, conversely, foodstuffs are not affected by it. Consequently, its uses have been found in the food industry.
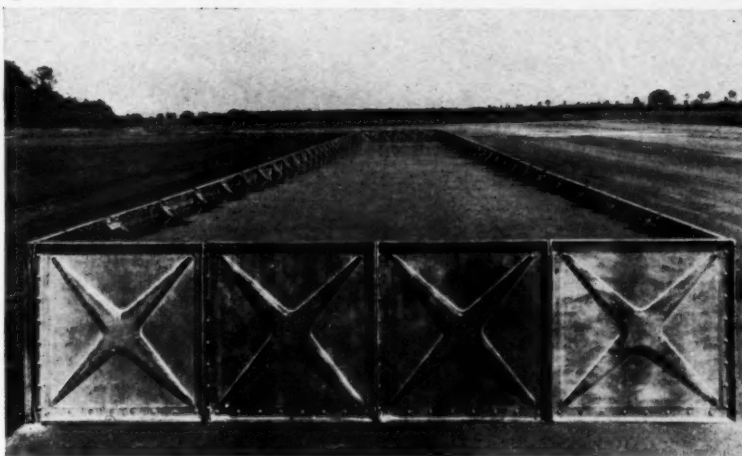
Static water tank of glass-fibre-reinforced plastic.

Nylon, too, has a limited use in this field. As with the last material its higher cost is a limiting factor. It is, however, used in fuel systems, for handling aliphatic compounds in chemical plant, in food processing and as a replacement for brass.

Polyethylene terephthalate

Polyethylene terephthalate is another specialist material which has a limited, but highly successful, sphere of use. It has low gas-permeability, light weight, extreme flexibility over a wide temperature range, good chemical resistance, high abrasion resistance, and great strength. It is one of the few materials which can be used to convey high test peroxide and which remains flexible when conveying liquid oxygen and liquid methane. It is resistant to oils, fats and solvents, and so should have a future in food processing.

Polyester reinforced with fibre-glass is in a different class from the foregoing material. It is thermosetting and consequently resistant to high temperatures. Because of its high mechanical strength it is the only plastic which approaches metals as a material for the construction of chemical plant in respect of its resistance to high pressures and temperatures. However, its resistance to chemicals is low, particularly to alkalis. The main uses are for salt solutions, and water piping in installations where sudden shock might be experienced, or when its high strength is called for. A steam generating plant in Los Angeles uses 12-in. polyester pipe.

The foregoing remarks apply equally well to reaction vessels, storage tanks, etc.

However, greater strength is often

needed, and a combination of these materials, for example a fibre-glass polyester/PVC laminate, gives a material with the strength of polyester reinforced with fibre-glass and the chemical resistance of PVC.

Duct work and ventilation systems

In the field of duct work and ventilation systems, rigid PVC and fibre-glass-reinforced polyester are rapidly replacing metal protected by organic coatings. The great strength of metals is not often required and this, coupled with the lower costs of fabrication, makes this application eminently suited to plastics. Plastic duct work has a far superior chemical and corrosion resistance than metal. It requires no protective coating, whereas the protective coating needed by metal ducting, both inside and outside, needs periodic maintenance. Moreover, it is lighter than metal by a factor which may be as great as 10 to 1. These advantages give plastics a great future in duct work, and it is very probable that a very high percentage of existing metal ducts will eventually be replaced by plastics.

Organic linings, mortars and cements

Natural rubbers, the most frequently used material for linings, do not stand up to severe chemical attack, and under these conditions may be replaced by PVC or furan resins. The linings may comprise of sheet applied by adhesive and with all joints welded, or it may be a thick coat built up by brushing, spraying or dipping. The following materials are used for linings:

Natural rubber, which is widely

TEMPERATURE MEASUREMENT AND CONTROL

I — Thermocouples

By E. W. Jackson, A.M.C.T., A.M.I.Chem.E.

By joining two dissimilar metals at their extremities and subjecting one of the junctions to a source of heat a thermoelectric current is produced. This principle is the basis of one of the most common types of temperature measurement used in laboratory and industry, the thermocouple. This article gives the historical development of thermocouples and endeavours to put forward some equations representing the approximate relationship between temperature and e.m.f. Various methods of measuring e.m.f. as well as ways of compensating for variations of cold junction temperature are described. A selection of metals that can be used together with their temperature limitations is given. It is of interest to note, for instance, that recently new combinations of metals have extended the range of temperature measurement by thermocouples to 2,800°C. This review therefore is of interest to those wishing to gain further information about the rapidly growing techniques of temperature measurement and control.

IN 1821 T. J. Seebeck showed that an electric current could be produced by thermal means. He joined a copper wire and a bismuth wire at their extremities and found that when one of the copper-bismuth junctions was heated an electric current was produced; he also found a similar effect using other combinations of metals. The complementary effect that the passing of an electric current into a circuit of two dissimilar metals caused heating in one junction and cooling in the other was demonstrated by J. C. A. Peltier in 1834. Later, W. Thompson showed that an electric current was produced in a single metal where a temperature gradient existed. With lead the current is transient, and this metal is often used for comparison purposes.
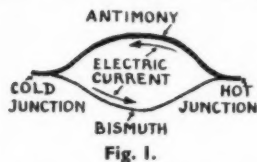
Fig. 1.

The arrangement of different metals producing an electric current is called a thermocouple (Fig. 1), and the magnitude of the e.m.f. depends upon the temperature difference between the hot and cold or reference junction, the metals which are used and the actual temperature. Within certain temperature limits the e.m.f. is proportional to the temperature difference for a particular combination of metals. With most thermocouples the e.m.f. at first increases in propor-

tion to the temperature rise, but on further heating the e.m.f. falls off to zero; if the temperature is again increased, the current flow is reversed. The point at which the e.m.f. reaches a maximum is called the neutral point, and the temperature at which it occurs is the neutral point temperature (Fig. 2). With some combinations of metals, the neutral point is not reached because it is above the melting point of one or both of the metals.

A perfect theoretical explanation of thermoelectric currents is not yet available, but some equations have been proposed which represent the approximate relationship between the e.m.f. and temperature of a thermocouple:

$$\log E = A \log t + B$$

or where the cold junction temperature is at 0°C.:

$$E = Xt^2 + Yt + Z$$

where:

E = e.m.f.

t = temperature

A and B are constants depending on the thermocouple metals and cold junction temperature.

X, Y and Z are constants depending on the thermocouple metals.

Following the discovery of thermoelectric currents, attempts were made to use thermocouples for the measurement of temperature, but it was not until 1881 that success was achieved. The main reason for the delay was that the metals used were not sufficiently pure, or they were used under conditions where their purity was affected, and their thermoelectric properties did not remain constant.
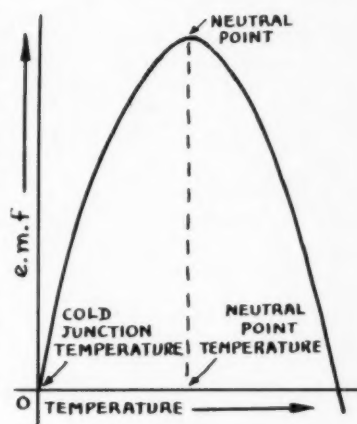

Fig. 2.

To use a thermocouple for the measurement of temperature, it is necessary to measure accurately the e.m.f. produced. Apart from purely scientific work, the measuring instruments are provided with temperature scales, and two methods of measurement are used.

Methods of measuring e.m.f.

In the deflectional method a double-pivoted millivoltmeter is normally used. The instrument should have as high a resistance as possible so that the resistance of the thermocouple and connecting leads represents a small proportion of the total circuit resistance. A typical instrument is shown in Fig. 3.

The potentiometric method is a more accurate one. Since it is a balancing method it eliminates any

error caused by changes in the resistance of the thermocouple leads. A simple potentiometric circuit is illustrated in Fig. 4. Standardisation is carried out by closing the circuit to the standard cell and adjusting the variable resistance R_1 until the galvanometer deflection is zero; the circuit is next closed to the thermocouple, and the slide-wire is adjusted until the galvanometer deflection is zero. The temperature is then indicated on the temperature scale attached to the slide-wire. The starting point of the scale is governed by the potential drop of resistance R_2, and the resistance R_3 takes up the residual e.m.f. of the dry cell. The total value of the resistances R_1, R_2 and R_3 is chosen so that the current flow is low enough to ensure that the dry cell has a reasonable life.[1]

Cold or reference junction temperature

As the temperature difference between the hot and cold junctions influences the e.m.f. developed by a thermocouple, then for accurate temperature measurement the cold junction temperature must be known or the cold junction must be maintained at a constant temperature. Alternatively, automatic devices which compensate for cold junction temperature variation may be used.

Base-metal thermocouples have an almost linear temperature-e.m.f. rela-

Fig. 5. Cold junction box made by Elliot Brothers Ltd.

tionship[2] throughout the temperature range for which they are suitable and, if the cold junction temperature is known, an arithmetical correction may be applied to the measurements to compensate for any temperature variation. This technique cannot be used with rare-metal thermocouples. Another method of correction, which can be applied to a direct reading instrument, is to arrange for the cold junction to be located in the measuring instrument. The zero of the instrument is then adjusted to room temperature before temperature measurements are taken.

Manual methods of compensation for variation in cold junction temperature are inconvenient. In scientific work the cold junction may be kept at 0°C. by immersion in melting ice, or the cold junction may be kept at constant temperature in a compart-

Fig. 3. Double pivoted millivoltmeter made by Cambridge Instruments Ltd.

ment which has its temperature thermostatically controlled. For works use a cold junction box may be used (Fig. 5); this consists of a vacuum flask filled with oil in which the cold junction is immersed. Another method to obtain a constant temperature is to bury the cold junction in the ground. At 10 ft. below a building, the temperature has been found to remain remarkably constant throughout the year.[3]

Automatic compensation

Automatic compensation is the most usual method of dealing with variations in cold junction temperature. With deflectional measuring instruments, compensation is effected by locating the cold junction in the measuring instrument. A bimetallic spring is incorporated in the instrument and is attached to the control spring; as the bimetallic spring expands or contracts with changes in temperature it automatically adjusts the zero of the instrument to the cold junction temperature.

In potentiometric circuits, the method of automatic compensation for variations in the cold junction tem-
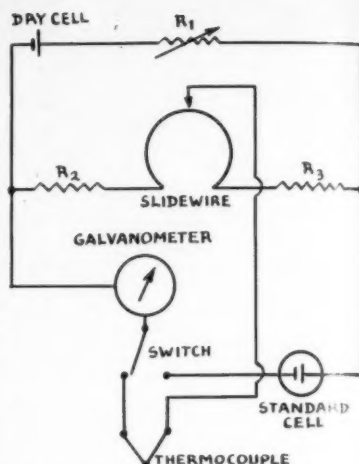

Fig. 4. Simple potentiometric circuit.

perature is to position the cold junction in the instrument. An additional e.m.f. is then added to the circuit equal to the error caused by variation in the cold junction temperature; the arrangement is shown in the circuit diagram of Fig. 6. If the potential drops across resistances R_2 and R_4 are identical, there is no additional e.m.f., and the e.m.f. measured will be that of the thermocouple. If the resistance of R_4 is increased, the potential drop across the resistance increases so an additional e.m.f. will be added to the thermocouple, and the total e.m.f. will be measured. The addition of this compensating e.m.f. is done automatically by fabricating the resistance R_4 in a material, such as nickel, having an electrical resistance which is sensitive to temperature changes. The extent of the compensation depends on the ratio of the resistances R_4 and R_5.[4]

The potentiometric temperature measuring instrument (Fig. 7) is a manually balanced type. Manually balanced instruments can be inconvenient, and instruments are available in which the balancing is automatic. The self-balancing instruments can also be provided with recording mechanisms.

Metals for thermocouple elements

The choice of metals for thermocouple elements is governed largely by the temperature range to be covered. Combinations of metals, which have their neutral point within the temperature range where measurements will be made, are of no value. Another factor to be considered is that the operating conditions must not cause any change in the composition of the
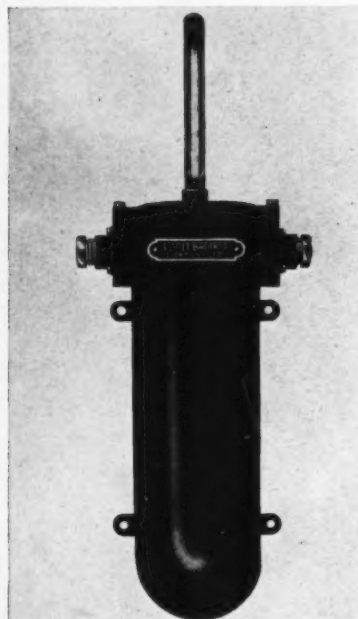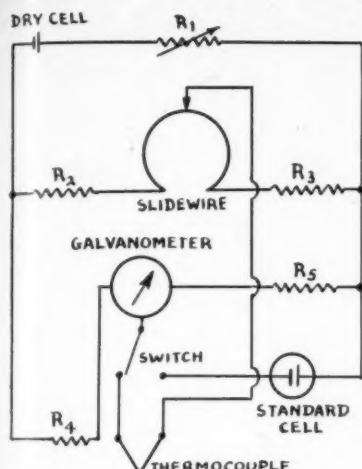
Fig. 6. Automatic compensation for cold junction temperature variation.

metals, otherwise there may be a change in the instrument calibration.

These limitations considerably reduce the combinations of metals which may be used as elements in thermocouples for temperature measurement. Table 1 lists suitable combinations of metals and their temperature limitations. For temperatures up to 1,100°C., base-metal thermocouples are satisfactory. Copper *v.* constantan is used for low-temperature work in laboratories. Chromel *v.* constantan gives a higher e.m.f. for a given temperature difference and is suitable for use at low temperatures. Where iron is used as one of the metals, care must be taken that the temperature is not too high otherwise the iron will deteriorate rapidly in an oxidising atmosphere. Chromel *v.* alumel is the most commonly used combination of metals; it is suitable for use in oxidising atmospheres, but it may suffer attack in reducing atmospheres.

For work of the highest accuracy and for use at high temperatures, rare-metal thermocouples are used; platinum-rhodium *v.* platinum combinations must be protected against attack by metallic vapours and furnace gases. As the e.m.f. generated by these thermocouples is comparatively small, very sensitive measuring instruments must be used with them.

Recently new combinations of metals have been introduced which extend the range of temperature measurement by means of thermocouples to 2,800°C.[8] Iridium *v.* 60% iridium-40% rhodium may be used in an oxidising or neutral atmosphere up to 2,000°C. It is embrittled if used under reducing conditions for long periods. Iridium *v.* tungsten is suitable for use

up to temperatures of 2,300°C. in an inert atmosphere such as argon or helium. The combination may be used for short periods under reducing conditions, but continued use will cause embrittlement of the iridium. This thermocouple gives the highest e.m.f.-temperature relationship of any thermocouple in the high-temperature ranges. Tungsten *v.* tungsten-rhenium may be used in reducing or inert atmospheres up to temperatures of 2,800°C.

For most applications the metals used for thermocouple elements are in the form of wire, but for special applications other forms are used. For the measurement of the temperatures of surfaces the metals are in the form of strips (Fig. 8). The metals are usually joined together by butt welding at the hot junction.

Protecting tubes for elements

With the exception of thermocouples which are made for special applications, it is usual to protect the metals. This is achieved by supporting the wires in porcelain insulators (Fig. 9), and surrounding them with a protecting tube made from a corrosion-resistant material. A complete thermocouple is illustrated in Fig. 10. A list of some of the materials used for the fabrication of protecting tubes is given in Table 2. A disadvantage in the use of protecting tubes is that they delay the response of the thermocouples to temperature changes.

Fig. 7. Manually balanced potentiometric temperature measuring instrument by George Kent Ltd.

Compensating leads

The cold junction of an industrial thermocouple is usually positioned in the e.m.f. measuring instrument by extending the thermocouple leads. However, the measuring instrument may be a considerable distance away from the equipment in which the temperature is being measured and, if it is a rare-metal thermocouple, it would be very expensive to extend the leads. In these cases, extension (compensating) leads made from base metals or base-metal alloys are used (Fig. 11). The metals are chosen so that they have the same thermoelectric characteristics as the thermocouple between 0° and 100°C., and this means that the temperature of the junction between the leads and the thermocouple must be kept within this temperature range.

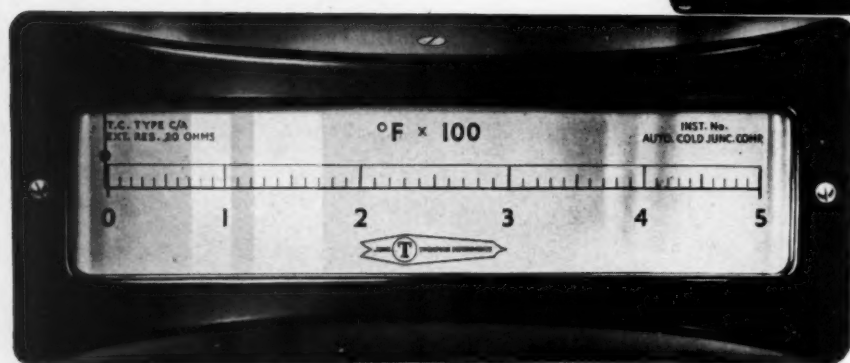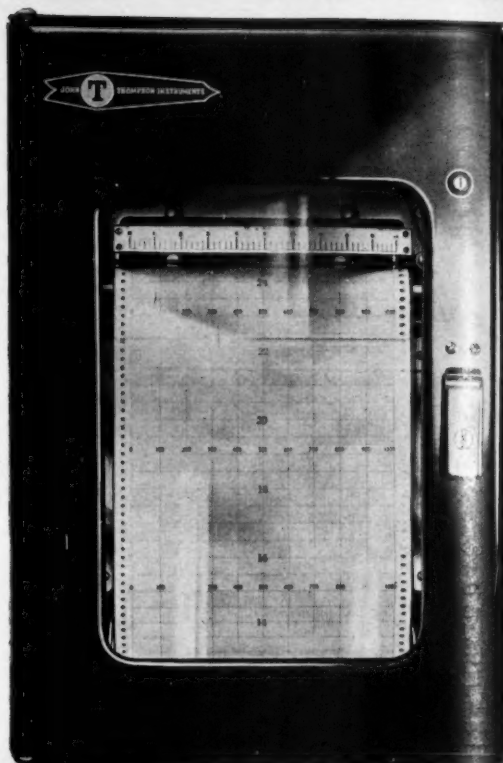### Table 2. Materials for protecting tubes

Material	Maximum temperature continuous operation
	°C.
Copper	500
Mild steel	650
Monel	750
Stainless steel	950
Inconel	1,000
Silicon	1,200
Mullite	1,500
Recrystallised alumina	1,750

Installation

The position and depth of insertion of the thermocouple into the equipment must be such that stagnant areas are avoided, and the temperature measured is representative;[6] direct flames should not be allowed to impinge on the protecting tube. The depth of insertion into the equipment must be sufficient to prevent low readings due to thermal conduction along the protecting tube and wires. It is recommended that the depth of insertion should be at least 20 diameters of the protecting tube.[7] Where high temperatures are to be measured, the thermocouple should be installed

Table I. Combinations of metals for thermocouples

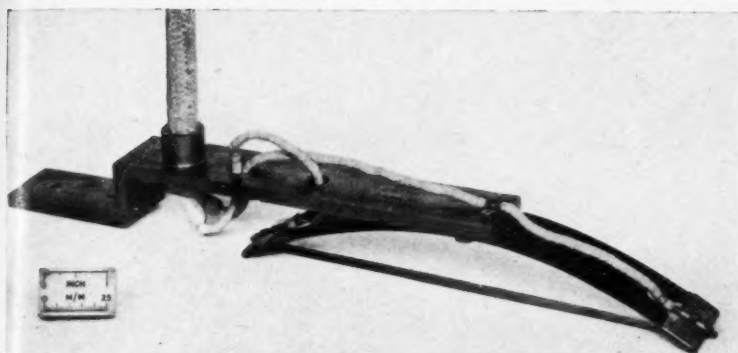| Combination	Temperature range for continuous use
	°C.
Copper *v.* constantan	−200 to 400
Iron *v.* constantan	−200 to 900
Chromel *v.* alumel	0 to 1,100
Platinum *v.* 13% rhodium-87% platinum	0 to 1,400
20% rhodium-80% platinum *v.* 5% rhodium-95% platinum	0 to 1,600
Iridium *v.* 60% iridium-40% rhodium	500 to 2,000
Iridium *v.* tungsten	500 to 2,300
Tungsten *v.* tungsten-rhenium	500 to 2,800

Fig. 8. Instrument for measuring the temperatures of surfaces. The metals are in the form of strips. Made by Cambridge Instruments Ltd.
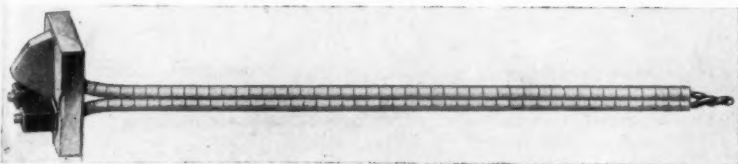

Fig. 9. The picture shows a thermocouple made by Negretti and Zambra Ltd. To protect the metals the wires are supported with porcelain insulators and surrounded with a corrosion-resistant tube.
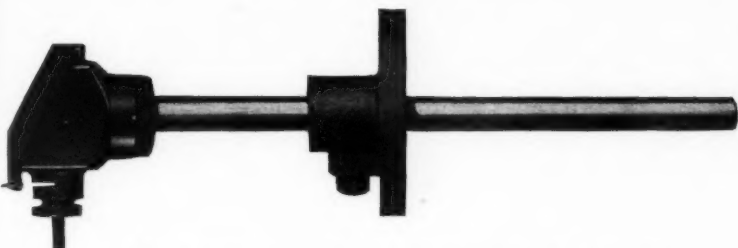

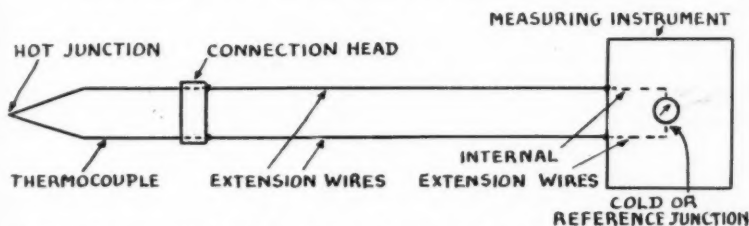Fig. 10. Complete thermocouple made by Negretti and Zambra Ltd.

Fig. 11. Compensating leads made from base metals where the thermocouple is made from rare metals.

NEW INSTRUMENTS

As part of this month's special feature on Temperature Measurement and Control a number of new instruments in this field are described in the What's New section of the journal. This appears on pages 149 to 152.

in a vertical position to prevent sagging of the tube.

It is important to use the correct type of extension wire for the particular thermocouple; whenever possible the thermocouple leads should be installed in earthed conduit, and they should be kept at least 1 ft. away from any wires carrying alternating current to avoid induced current effects. Other electrical wires should never be carried in the same conduit as thermocouple wires. Where measuring instruments are connected in parallel for operation from a single thermocouple, the circuit should be analysed for possible feed-back effects.

Maintenance

The checking of thermocouple calibrations[6, 8] should be a routine, and a frequency of once a month is suggested for base-metal thermocouples. It is desirable as far as possible to check the thermocouples in the position in which they are used. Where this is impractical, and the thermocouple must be removed, then on reinsertion the depth of insertion should not be changed. The reason for this is that errors are caused by inhomogeneity in the wire in the region of temperature gradients. Sometimes where the average life of the thermocouple has been established it is more convenient to replace the thermocouple element than to carry out periodic calibrations.

Thermocouple wires should not be left where they can come into contact with oil or grease, and should never be handled with greasy fingers. The insides of protecting tubes should always be kept clean and, where the presence of oil in metallic tubes is suspected they may be cleaned by heating to redness with a current of air passing through them to burn off any residue.

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[3] ' Some Methods of Measuring Temperature,' Cambridge Instrument Co. Ltd., Technical Monograph No. 1, 1957, page 8.
[4] Reference 1, page 601.
[5] Engelhard Industries Ltd., private communications, Jan. 14, 1960, and Feb. 11, 1960.
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[7] ' The Efficient Use of Fuel,' H.M.S.O., 1944, 732.
[8] R. W. Porter and D. M. Considine, ' Chemical Engineers' Handbook ' (editor, J. H. Perry), 3rd ed., 1950, page 1273.

2 – Temperature Control Data Logging Equipment

By W. J. A. Donnelly*

Hundreds of thermocouples throughout the plant are sampled every fifteen minutes by a monitoring system which can print out both a half-hourly log and an off-normal abstract while giving alarm signals where necessary. The operating principle is based on self-balancing potentiometers, equipped for digitising, and extensive testing facilities are provided.

THE Sunvic equipment described here provides temperature monitoring and data logging for a continuous chemical process plant of Imperial Chemical Industries Ltd.

The complete assembly, which weighs approximately $4\frac{1}{2}$ tons, is in three sections, with individual key switches, plugs, limit indicators, temperature indicators and alarm lamps, all panel-mounted. The rear of each wing cubicle carries input relays and limit-setting potentiometers and space is provided for portable limit-setting calibration gear.

The central cubicle contains the recorders, common apparatus, jumper frames and control units, and includes the logging printer. The alarm printer is mounted separately.

The equipment is intrinsically safe in explosive atmospheres, is accurate to $\pm2°C$. and limits can be set to $\pm1\%$ of full scale.

General description

Information is derived from 440 chromel/alumel thermocouples, all within the range $0°$ to $300°C$.; these provide an output of approximately 0 to 12 mv. For monitoring purposes, any temperature can be displayed on either one or two potentiometric indicators or, if required, a selection of temperatures may be recorded on the three 12-point potentiometric recorders.

For logging purposes, any of the 440 thermocouple outputs can be routed to the logger, so that they are scanned every 15 min. The value of each point is compared with pre-set upper and lower limits, and any deviation is printed out.

The output from each thermocouple is connected both to a manually operated key selector switch and an automatically operated input relay. This provides either temperature indication or automatic scanning. Three circular scale indicators are fitted in each wing cubicle, the centre one showing the temperature of any point when the appropriate switch is depressed. The indicators either side of this meter show high and low limits for the particular point.

When the key switch is in its mid-

```
0 6 M : 0 4 D : 1 0 H

3 0 : T 0 1 : 1 2 3 H
3 0 : T 0 2 : 1 2 3
3 0 : T 0 3 : 1 2 3 L

3 0 : Pe 2 1 : 1 2 5 H
3 0 : Pe 2 2 : 2 4 3
3 0 : Pw 0 1 : 1 9 8 L

3 0 : Se 1 7 : 0 0 0 C
3 0 : 16 1 1 : 5 1 2 C
3 0 : 17 2 2 : 0 1 7
```

Fig. I. A typical log printer strip identifies each point by symbol and number, and indicates whether measured value is high or low; it prints out-of-limit conditions in red

```
1 1 M : 2 6 D : 1 5 H

3 1 : Pe 0 0 : 1 3 3 H
3 1 : Pe 0 1 : 1 3 3 L
3 1 : Pe 0 2 : 1 3 3 H

3 1 : Pe 0 3 : 1 3 4 L
3 1 : Pe 0 4 : 1 3 5 H
3 1 : Pe 0 5 : 1 3 4 H

3 2 : Pe 0 6 : 1 3 2 H
3 2 : Pe 0 7 : 1 3 3 H
3 2 : Pe 0 8 : 1 3 3 H

3 2 : Pe 0 9 : 1 3 4 H
3 2 : Pe 1 0 : 1 3 4 H
3 2 : Pe 1 2 : 1 3 5 H
```

Fig. 2. This monitoring printer strip records only out-of-limit conditions and an alarm is operated at the same time.

position for scanning, there are two alternative signal routes. One is through an input relay to the logger, the other through a jack socket to which may be plugged one of three 12-point self-balancing potentiometric recorders. In the latter case, use of any jack plug automatically starts the chart motor of the appropriate recorder.

When the key switch is in the off position, input from the point concerned is not subjected to the normal limit comparison procedure of the logging equipment. However, although no print-out action for the point takes place, an input signal is still available at the jack socket.

If a recorder plug is in use, or if a key switch is set for 'indicating,' there is no print-out action for that particular point. Nevertheless, the scanner dwells on it for the allotted 2-sec. period.

Each key switch is spring-loaded to return to 'Scan' from 'Indicate,' but may be locked in the 'Off' position.

Print-out

Two printing machines are provided. One is known as the log printer, and is housed in the scanner cubicle. The other, known as the alarm printer, is housed separately at a monitoring desk.

Both printers present data in a nontabulated form on continuous strip. The log printer, used at predetermined intervals, is fitted with an automatic guillotine which is brought into action at the end of each log. All temperatures are recorded: those that deviate in red and those within prescribed limits in black.

Usually a log is printed every 30 min., that is, for every second scan.
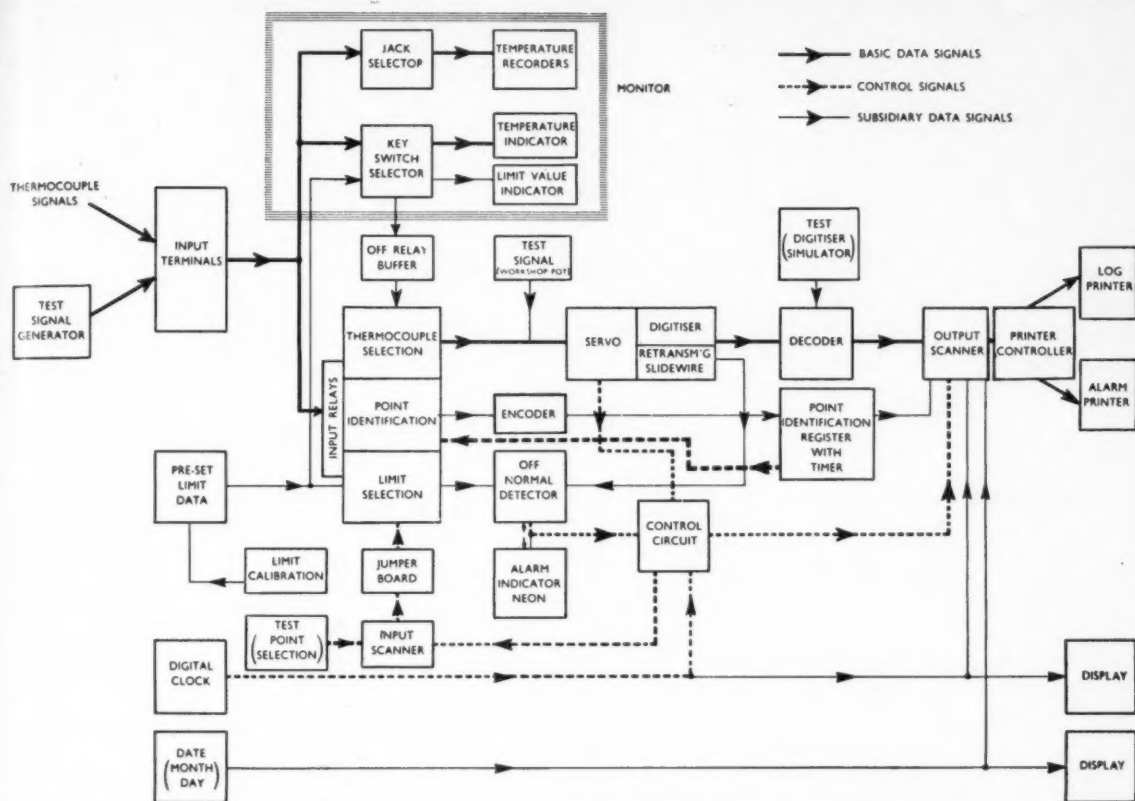
*A.E.I. Instrumentation Ltd.

Fig. 3. The general arrangement of this data logging and monitoring system which provides for manual testing and calibration as well as for indicating and strip recording of points selected by means of overriding key switches.

Alternatively, logging taking place at 15-min. intervals is known as 'continuous log.'

A typical log printer strip, shown in Fig. 1, records at the start of scan, month, day, hour and, after a two-line space, three test inputs. (Same nominal value but different limits.)

Each group of three points is followed by a one-line space. Each sampling yields the following data: time (min.); point number; value and symbol for high or low. Open circuit is recorded as 000C and decoder fault as 5C.

End of log is indicated by a space not less than 20 lines long, followed by a guillotine operating pulse.

Alarms

The other printer supplies the appropriate data only for those points found to be outside the pre-set limits. This machine is equipped for manual paper tear-off. The start of the scan, data presentation and spacing is generally the same as on the log printer. An example is shown in Fig. 2.

A neon lamp is provided for each point to give visual alarm if necessary.

On detection of an off-normal condition, it stays lighted until either the point returns to normal, or the alarm is cancelled by push-button. This shows at a glance those points where conditions deviate beyond the limits, in addition to the 'off-normal' print-out.

Circuits

Fig. 3 shows a schematic layout of the system as installed at the I.C.I. plant. Primary measuring elements for all points are chromel/alumel thermocouples. Cold junctions are held at a constant 45°C.

A scanner routes information through each input relay in turn to a common self-balancing potentiometer where the thermocouple signal is measured. The speed of scanning is 2 sec. per point and the scanning cycle is synchronised to start at the ¼ hr.

The potentiometer mentioned above carries a digitiser and re-transmitting slidewire for limit detection. The digitiser output is only used if print-out is required.

A jumper field is fitted so that the

thermocouples can be presented to the common measuring equipment in any sequence. A special jumper permits an 'end of log' signal to be introduced as required.

Each thermocouple input has associated with it a high and low limit-setting potentiometer. These are manually set against a portable unit consisting of two precision potentiometers, calibrated over the full temperature range, together with associated null indicators.

For the purpose of alarm detection, a valve-operated detector compares the voltage derived from the re-transmitting slidewire in the self-balancing potentiometer with voltage derived from the appropriate limit potentiometers.

Testing and faults

For testing purposes, a known input can be connected to the first three input points. Limits for these can be adjusted to give a high, normal and low print-out, the routing being as for a normal input. In general, test facilities are provided so that the

NUCLEAR NOTES

Indirect-cycle aircraft reactor

The U.S. Atomic Energy Commission has awarded the Blaw-Knox Co. a contract to conduct a study of the facilities required for testing an experimental indirect-cycle aircraft reactor.

The purpose of the study is to establish a basis for determining the most economical and practical method of providing the facilities needed for the testing programme to be conducted as part of the commission's aircraft nuclear propulsion programme. The study will also provide a basis for the development of design criteria for new facilities or the modification of the existing facilities that may be required.

All existing aircraft nuclear propulsion programme facilities were designed for and are being used in the development of a direct-cycle aircraft reactor by the General Electric Co.

In a direct-cycle, nuclear-powered turbojet engine, air is drawn through an intake into a compressor. The compressed air is then heated as it flows ' directly ' through the reactor core. (The reactor takes the place of the conventional chemical fuel combustion chamber in a turbojet engine.) As the air leaves the reactor it passes through the engine's turbine and out of the exhaust nozzle. The jets of hot gases leaving the nozzle provide thrust for the aircraft.

In an indirect cycle engine, the compressed air flowing through the turbojet engine is heated as it passes through a radiator which is part of a heat-exchanger system containing liquid metal coolant. The heat from the reactor is transferred to the radiator by the coolant. Thus the air is ' indirectly ' heated by the reactor.

Health protection

The O.E.E.C. has announced publication of the proceedings of the symposium on health physics in nuclear installations, which was held last May at Risø, Denmark. The symposium, which was attended by 120 scientists from research centres and nuclear installations in Europe and America, was organised by the European Nuclear Energy Agency with the collaboration of the Danish Atomic Energy Commission. The president d'honneur was Prof. Niels Bohr.

Topics discussed at the symposium included the fundamental scientific principles for the establishment of health protection standards, methods of measurement and control of radioactive contamination in working areas, the control of personnel contamination, practical problems of health physics in specific types of installation, and ways of meeting emergency situations.

The Risø proceedings represent a synthesis of current health physics theory and practice in the Western world.
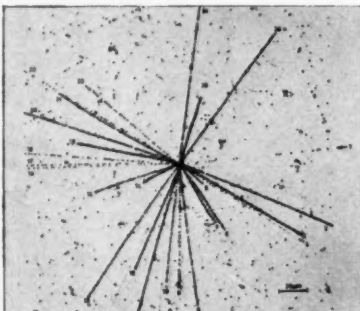
PROTON SYNCHROTRON

This is one of the first microphotographs of the disintegration of an atomic nucleus produced in special photographic emulsion by an artificially produced high-energy particle (track 1)—probably a proton of energy around 25 GEV —furnished by the CERN proton synchrotron.

The interaction of the incident particle with the nucleus gives rise to the creation of particles, principally pi and k-mesons, which are ejected in general with high speed and those that are charged produce tracks with a very low number of grains (tracks 4, 16, 17, 18, 22, 23).

Most of the 'black' and 'grey' tracks are produced by the charged fragments of the disintegrating nucleus. A more detailed analysis may eventually show that some of them are due to so-called 'strange' particles.

The particles which enter the emulsion (like track 1) come from a target of stainless steel, 1-mm. thick, bombarded by the internal beam of the proton synchrotron.

Nuclear ship hazards

The director general of the International Atomic Energy Agency has designated Mr. A. Lilar, president of the International Maritime Committee and Deputy Prime Minister of Belgium, to preside over a meeting convened by I.A.E.A. to consider problems connected with liability for damage caused by nuclear propelled ships.

Existing rules of liability do not adequately cover nuclear hazards; this lack is accentuated by the potential magnitude of damage in case of any large-scale release of radiation from nuclear ships, by possible far-reaching effects of a nuclear ship accident and the possibility that damages may remain undetected for a long period.

The absence of international rules in this field might therefore lead to insufficient compensation to the victims; claims which cannot be measured in advance and therefore cannot be financially covered might also be made against persons involved in the construction, operation or repair of nuclear ships.

In the invitation to participate in this programme, the director general pointed out the obvious need for international rules covering nuclear ship hazards. Both those states which are expected to licence nuclear-propelled ships in the near future, and those in whose territorial waters or ports nuclear ships might enter have an obvious interest in agreed rules as to liability, as have those states whose shipbuilding industry will participate in the construction or repair of atomic vessels.

Japanese power station

Mr. D. Yasukawa, president of the Japan Atomic Power Co., and Sir Roger Makins, chairman of the U.K.A.E.A., recently signed the heads of contract for the supply of natural uranium fuel elements for the nuclear power station which the General Electric Co. are to build in Japan for the Japan Atomic Power Co.

This contract establishes the main features which will govern the supply of new fuel and the repurchase of irradiated fuel during the first ten years of the reactor's operation. It is estimated that the value of new fuel will be about £3 million.

Particle Size Analysis in Routine Process Control

By A. G. Pendleton,* M.Sc., A.R.I.C., A.M.C.T.

A REVIEW of the range of instruments available for particle size analysis appeared in the November 1959 issue of this journal under the heading 'Particle Size Analysis for the Chemical Engineer.' The article was primarily concerned with the measurement of particle size distribution and, whereas an accurate knowledge of the distribution is essential when design data are required, it is of less importance in process control.

When particle size analysis is used in process control the primary demands made on the apparatus are as follows:
(1) Simplicity in operation.
(2) Rapid production of results in an easily assimilated form.
(3) Reproducibility independent of the operator and of the ambient conditions.

Simplicity is essential since a skilled operator can seldom be employed on shift work for economic reasons. Rapidity is essential, since the process itself is usually continuous and should adjustments to the plant prove necessary they must be made with the minimum of delay. Finally, reproducibility is of the utmost importance since without this guarantee the apparatus is of no value for the function under consideration.

To these three conditions should be ideally added a fourth—accuracy over a wide range of materials and of particle sizes. An instrument which has been built with these specifications in mind is the *Fisher* sub-sieve sizer. This apparatus is based on air permeability principles, but is said to incorporate certain refinements which make it possible to ignore many of the obvious sources of error in this method.

Principles of measurement using air permeability

The instrument embodies the principles of a particle size measuring apparatus assembled and used by Gooden and Smith,[1] who employed what is known as the air-permeability method for measuring the average particle size of a powder. Average particle diam. for the range of 0.2 to 50.0 microns can be determined with the instrument.

The method is based upon the fact that a current of air flows more readily through a bed of coarse powder than through an otherwise equal bed of fine powder, *i.e.* equal in shape of bed, apparent volume, and percentage of voids; but by reason of difference in general coarseness of material, differing in average pore diam. and in total interstitial surface. The permeability principle has been applied by Carman,[2] who used liquids rather than air, by Traxler and Baum,[3] by Dalla Valle,[4] by Lea and Nurse[5, 6] and others.

The mathematical formulae involved in calibrating the *Fisher* sub-sieve sizer are those derived by Gooden and Smith from earlier work by Carman. One of the important contributions of these investigators is the standardisation of conditions, which enables the particle size to be obtained through the use of the instrument chart without mathematical computation on the part of the user. The value of the average particle diam. obtained with this instrument is numerically equal to six times the total volume of the sample under test divided by the total surface of all the particles contained in this sample, regardless of particle size distribution.

Construction and mechanism

The sub-sieve sizer is composed of an air pump, an air-pressure regulating device, a precision bore sample tube, a standardised double-range air flowmeter, and a calculator chart, with accessory equipment necessary to correlate these parts into a unit. These parts are housed in a heavy wooden cabinet and the whole has been designed for simplicity of the measurement of particle size. The mechanism may be described, briefly, as follows:

The air pump builds up air pressure to a constant head in the pressure regulator. The air under this pressure head is conducted to the packed powder sample contained in the sample tube. The flow of air through this packed bed of powder is measured by means of a calibrated flowmeter, the level of the fluid in which indicates directly on the chart the average diam. of the powder particles.

Starting with fundamental equations relating the flow of fluid through a bed of particles to the physical characteristics of that bed, Gooden and Smith have derived the formula:

$$d_m = \frac{60,000}{14} \sqrt{\frac{NCFDL^2M^2}{(VD-M)^3(P-F)}}$$

in which
d_m = Average diam. in microns.
N = Viscosity of air, poises.
C = Conductance of the flowmeter resistance in c.c./sec./unit pressure (g./sq.cm.).
F = Pressure difference in g./sq.cm. across the flowmeter resistance.
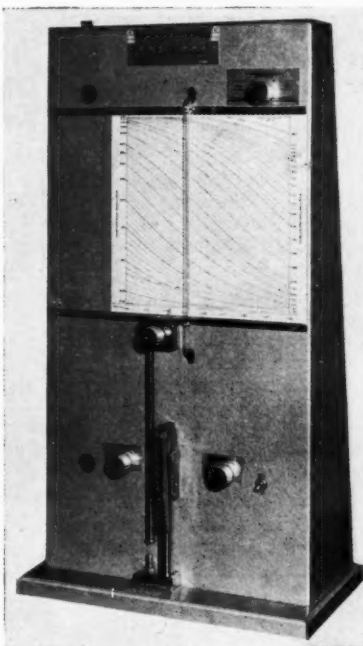D = Density of sample in g./c.c.
L = Length or height of the compacted sample, *i.e.* depth of bed, in cm.
M = Mass of sample in g.
V = Apparent volume of compacted sample in c.c.
P = Overall air pressure head in g./sq.cm.

By the expedience of using a sample weight equal in grammes to the true density of the material, of packing the

The sub-sieve sizer.

*Kek Ltd.

sample to a known degree, and of selecting and fixing several of the variables, the equation may be simplified to the extent that the average particle diam. is indicated by the value of F only, *i.e.* as far as the instrument is concerned, by the height of a column of liquid in a glass tube. In the sub-sieve sizer, it is not necessary to make an actual measurement of the height of the liquid column. Instead, by use of the calculator chart, the average particle diam. may be read directly.

If it is desired, the average particle diam. may be expressed in terms of S_w, equal to the specific surface of the powder in sq.cm./g. of dry powder; or in terms of S_o, equal to the specific surface of the dry powder in sq.cm./c.c. of equal solid material. These relationships are expressed in the equation:

$$d_m = \frac{6 \times 10^4}{pS_w} \text{ or } \frac{6 \times 10^4}{S_o}$$

$$S_w = \frac{6 \times 10^4}{d_m p} \quad S_o = \frac{6 \times 10^4}{d_m}$$

in which

p = True density of material from which the powder was made in g./c.c.

S_w = Specific surface in sq.cm./g. material.

S_o = Specific surface in sq.cm./c.c. of solid material.

Procedure

The procedure with the sub-sieve sizer may be described briefly by the following five operations:

(1) A sample of dry powder equal in grammes to the true density of the material is weighed out (to 0.01 g.).

(2) The sample is transferred to a precision bore tube closed at each end by porous brass plugs which are covered by filter paper discs.

(3) The sample in the tube is packed to a known porosity on the instrument, the porosity figure being read off from the calculator chart.

(4) The sample tube is mounted in position and the air pump switched on.

(5) The liquid level in the manometer tube will usually reach a maximum in less than 3 min. and the average diam. in microns may then be read off the calculator chart.

The stage of this procedure at which the human element has greatest influence is when the sample is packed. Porosity is defined as the ratio of the

air space in the sample bed to the total volume occupied by the packed sample. With many materials, only small and barely detectable differences in the average diam. will be noticed for the different porosities to which the bed is packed. In practice, however, it is advisable initially to make a number of determinations and then subsequently to select a porosity figure in the middle of the range over which the average diam. is constant. This porosity figure should then be quoted when the instrument is used for quality control. The operating conditions for any one instrument can therefore be specified in detail, *e.g.* 'An average diam. of 1.25 microns must be obtained using a sample weight of 2.79 g. packed to a porosity of 0.58.'

In order to ensure reproducibility between instruments a sub-sieve sizer calibrator has been developed. The calibrator is a synthetic ruby jewel with a precise orifice, mounted in a tube similar to a sample tube. When calibrating or standardising the instrument, the sample tube is replaced by the calibrator which acts on the air permeability principle as does a packed sample. Each calibrator is checked on a standard sub-sieve sizer which has previously been set to properly read the National Bureau of Standards powdered Portland cement sample of certified specific surface (Standard sample No. 114).

Conclusions

The whole estimation can be completed by a relatively unskilled operator in less than 10 min. Rapidity and easily assimilated results are obtained. Reproducibility of estimations made on the same or other instruments is ensured by use of the porosity scale and the calibrator. The range of the instrument embraces average particle diam. from 0.20 to 50.00 microns, and the use of dry air as the operating fluid ensures that the instrument can be used with a wide range of powders.

It is also worth pointing out that Lea and Nurse,[6] whilst they were uncertain as to absolute values obtained by air permeability methods, pointed out that their advantage was the case with which comparatively unskilled operators could obtain reproducible results. Furthermore, for many practical purposes it is sufficient to control a process by utilisation of a parameter which is itself some simple function of the particle size. Stairmand[7] has also pointed out the necessity for a method which can be operated by unskilled labour, which gives a rapid result, and which is not subject to personal errors or errors of method.

The makers do not claim that the *Fisher* sub-sieve sizer gives a result which is always accurate in the absolute sense, nor that it gives a particle size distribution. They only claim that it rapidly gives a result which may be reproduced by supplier, customer and by plant control analysts.

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Data Logging

location of faults can be carried out on a unit-to-unit basis, and by the use of built-in test gear.

The detection of an unused binary code will cause the digit concerned to be printed as 5, and the symbol as C, in red. It will appear only by the printer on which the information would have been displayed had the code been correct. Thus, should the machine concerned be the alarm printer, it will be known that the true value is outside limits, and the alarm neon will be lit normally. A lamp marked ' False reading ' is also lit.

WHAT'S NEW

Plant • Equipment • Materials • Processes

CPE reference numbers are appended to all items appearing in these pages to make it easy for readers to obtain quickly, and free of charge, full details of any equipment, machinery, materials, processes, etc., in which they are interested. Simply fill in the top postcard attached, giving the appropriate reference number(s), and post it.
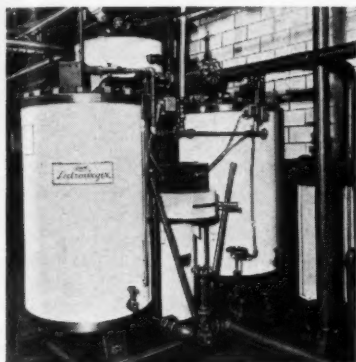
Water - cooled dual adsorber compressed air drier.

Driers

A range of drying equipment designed to maintain a constant low level of water vapour in air, gases or organic liquids is offered by G.W.B. Furnaces Ltd.

The basic element of the drier is an adsorber unit which contains a granular hygroscopic material.

To maintain moisture removal, G.W.B. *Lectrodryers* intended for continuous operation have twin adsorbers. With the twin-tower machine, the moist substance passes through one adsorber for a period of time and then the flow is switched to the second tower. Meanwhile the first adsorber is reactivated by applying heat to release adsorbed water, so that the unit is soon ready to go back on stream.

Single adsorber driers are said to be suitable for intermittent operation, where drying is required only during the working day, and reactivation can be carried out during the night.

A range of driers is available from the 68-lb. model handling up to 20 cu.ft./min. of air to large custom-built models for special applications.

Applications for which the driers are recommended include air conditioning, drying compressed air, and drying hydrogen for sintering furnaces.
CPE 1474

Tunnel burners

Barlow-Whitney Ltd. offer airblast tunnel burners which have been designed to meet industry's demands for faster and more efficient process heating to keep pace with increased production.

They are said to be ideal for direct local convection heating applications such as in forge work, billet heating and glass polishing, apart from installation in boilers, furnaces, ovens and similar industrial plants employing the principle of jet recirculation. The burners incorporate their own combustion chambers and use airblast injection from a simple centrifugal blower to entrain gas at atmospheric pressure.

Two standard types have been developed utilising research data made available by the Gas Council's Midland research station. Series 'B' circular discharge models have metal-cased combustion tunnels for low- and medium-temperature applications (to 500°C.) and Series 'C' slot discharge models for high-temperature applications (to 1,500°C.) have refractory-cased combustion tunnels suitable for setting in brickwork. Capacities range from 0.5 to 10 therms/hr. on town gas (475 B.Th.U. calorific value) when operating on 15-in. gauge air pressure. Larger and special models and units for use with butane and other gases are available. **CPE 1475**

Flaked form long-chain amines

Long-chain amines such as *Armeen HT* (made from hydrogenated tallow) and *Armeen* 18 (pure octadecyl amine), together with their acetate salts, have melting points in the region of 55°C. which make them difficult to empty from drums. In many cases, to facilitate removal from the drum, the material has to be melted, an expensive and awkward operation.

Armour Hess Chemicals Ltd. now supply these chemicals in flaked form, packed in 100-lb.-net fibre kegs. They are free flowing and easily handled, which is of particular advantage where these cationic surface-active chemicals are used. **CPE 1476**
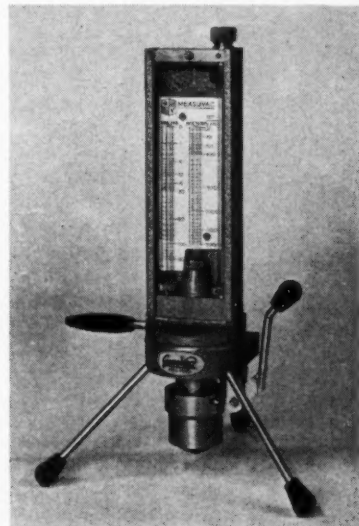
McLeod gauge

A McLeod gauge, covering a range of pressure hitherto not possible, has been made by Genevac Ltd.

The standard model covers the range from 150 mm. to 1 micron. This is achieved by depressing a lever which gives accurate readings simultaneously on two scales, one reading from 2 to 150 mm. and the other 1 to 2,000 microns.

On depressing the handle the mer-

McLeod gauge.

cury rises in the three tubes and the rising level in the left-hand intake tube is adjusted to the set mark position. With this held steady a pressure reading is taken on the scale, appropriate to the pressure range. Once the reading has been taken the operating lever is released and the mercury returns automatically to zero for the next reading. This eliminates the possibility of mercury being left in the tubes and resultant damage if the pressure should rise to atmospheric.

The glass work is easily removed by means of the demountable ' O ' ring joints, cleaned in the normal way and replaced again in a very short time. Where necessary the whole mercury tank can be dismantled by means of the four clamping screws and the complete mechanism exposed for this operation. It is necessary to remove the mercury from the gauge before dismantling the tank. **CPE 1477**

Face shield

The FV 8 swivel face shield is a new version of Pyrene-Panorama's ' heavy-duty ' face shield. It is designed to achieve a greater degree of ventilation, thereby improving its de-misting properties.

An aluminium strip, swivel mounted on the screw adjustable head harness, carries a heat-reflecting or clear or coloured acetate *Celastoid* screen which can be supplied in 6, 8, 10 and 12-in. depths. The screen is readily removable, being held in position by non-ferrous set screws and plastic-covered nuts which are secure when hand tight. **CPE 1478**
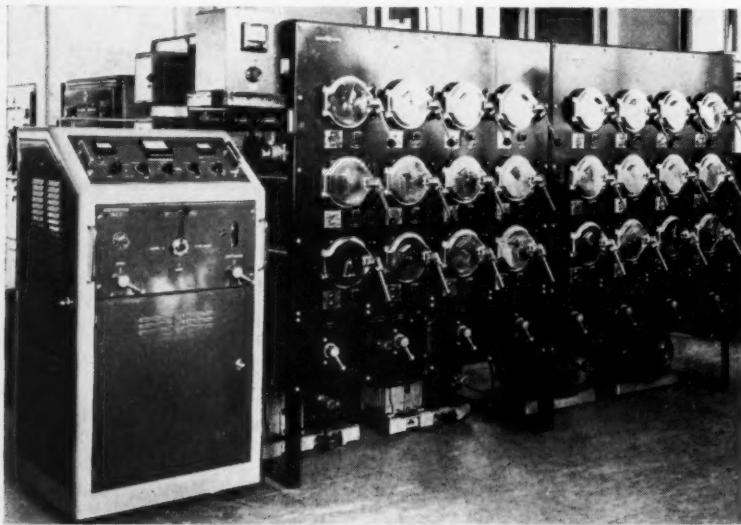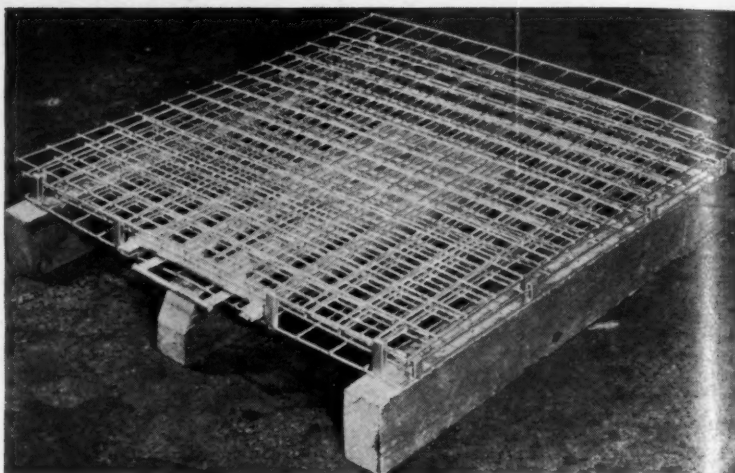
BULK CONTAINER

A collapsible intermediate size bulk container for chemical powders, flakes, etc., has been introduced by the dyestuffs division of I.C.I.

This container, which is constructed of Weldmesh *Ref. No. 35 (3 × 3 in. mesh, 5 s.w.g.) is capable of carrying $\frac{1}{2}$ to $\frac{3}{4}$ ton of material in a large two-ply paper liner. It is collapsible for return empty and can be handled by pallet or fork truck.*

To overcome emptying difficulties a sliding closure in the base has been designed which allows the contents to be dropped easily in the quantities required.

The Weldmesh *is supplied by the manufacturers, the B.R.C. Engineering Co.* **CPE 1479**

Sensitive leak detector

A leak detector, made by La Compagnie Francaise Thomson-Houston, which is designed to detect leaks in equipment which, for efficient and safe operation, requires to be completely sealed, such as nuclear equipment, distillation and refrigeration equipment, pumping installations, heat exchangers, condensers and boilers, is offered by Leland Instruments Ltd.

The instrument, type TMH 105A, is based on the principle of detection of helium gas by a miniature mass spectrometer. It is capable of detecting, locating and measuring leaks as small as 10^{-12} c.c./sec. To enable detection to be achieved the proportion of helium required in any other gas is as little as one part in 10 million. Response time is rapid and power consumption is 800 w.

The spectrometric chamber employs double deflection of 180°, so attaining great stability of operation and a high sensitivity.

Two pumping units are incorporated in the vacuum circuit, a two-stage mechanical pump of high capacity and a silicone oil vapour diffusion type, cooled by compressed air. This pumping assembly maintains a very low pressure in the test cavity which can be reduced to below 10^{-6} mm. Hg.

A helium flow meter, controlled helium jet and a helium sensing probe are additional features of the instrument and provision is made for remote indicating meters and audible alarms. **CPE 1480**

Sensitive leak detector being used to detect leaks in individual nuclear fuel cans.

Thermocouple wire

There have been additions to the range of Philips *Thermocoax* (miniature thermocouple) wire.

Type 2BB Ac 10 consists of two wires of alumel in a stainless-steel sheath with an overall diameter of 1 mm. This material can be used—with two junctions of chromel-alumel —for measuring differential temperatures.

Types 2AB Ac 15 and 2AB Ac 20 are chromel-alumel wires in a stainless-steel sheath with overall diameters of 1.5 mm. and 2.0 mm. respectively.

Type 1 Nc I 05 is a heating element of *Nichrome* in an *Inconel* sheath with an overall diameter of 0.5 mm.

Thermocoax wire has been designed for measuring a wide range of temperatures under extreme conditions, *e.g.* surface and working temperatures of all kinds of heat-treated materials, of furnaces, working machine parts, and heating and cooling installations. It is recommended for use in atomic energy plants and steel mills.

Available from Research & Control Instruments Ltd. **CPE 1481**

Liquid chillers

A range of six standard liquid chillers of from 1.5 to 20 b.h.p., capable of being installed in 16 variations by combination with various types of heat exchanger are being marketed by Carter Thermal Engineering Ltd.

The machines are designed principally for cooling water or ethylene glycol brine for air conditioning or industrial processing and can give leaving temperatures between –20 and
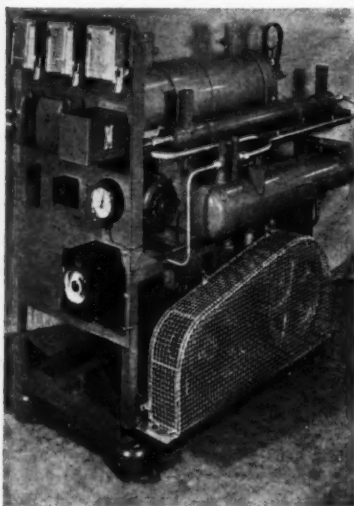
Liquid chiller.

TEMPERATURE SELECTION

An Isojacket *incorporating two interleaved heating circuits—one enabling the temperature to be maintained at the selected level, the other catering for the quick rise in temperature specified—has been made by Isopad Ltd. in answer to a request from W. G. Pye & Co. Ltd. for heating equipment for the 4-ft. long × 2½-in.-diam. heating column of the Pye argon chromatograph unit. The requirements were: provision for any selected temperature up to 250°C., with ½° accuracy, even distribution of temperature over the whole length and a temperature rise at the rate of 10°C./min.* **CPE 1482**
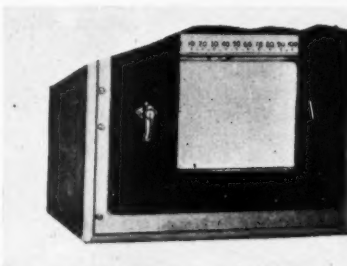
+65°F. High-efficiency inner-fin condensers and evaporators are used in a system with fluorinated hydrocarbon refrigerants. The design aims at compactness and self-sufficiency; all pipework and electric wiring required for operation are installed before machines leave the manufacturer. It is capable of extracting about 60,000 B.Th.U./hr. **CPE 1483**

Adjustable contact thermometers

The *Jumo-Shandon* adjustable contact, mercury thermometers are said to be suitable for maintaining a constant temperature at a readily adjusted value in water baths, reaction vessels, vats, incubators, drying ovens, sterilisers, distillation apparatus and similar process equipment.

The instrument consists of an upper and a lower section, in each of which is an identical scale. The lower scale indicates the prevailing temperature while the identical upper scale is used for setting the required operating temperature. This setting is effected by rotating the magnet on top of the thermometer, which causes the sealed-in micrometer screw to

turn, thereby moving the small index marker up or down against the upper scale. Affixed to this marker is a fine contact wire which reaches down into the lower capillary.

The length of the wire is such that as the mercury rises in the lower capillary it contacts the wire at the temperature set on the upper scale. A second, fixed contact wire is sealed into the bottom of the lower capillary. The circuit is thus closed, causing the interposed relay to switch off the heater or any other device to be controlled. This process can be reversed, if necessary, so that, for example, a cooling unit is switched on when the relay circuit closes.

The two connections from the fixed and adjustable contacts are brought to a two-screw terminal, protected by a bakelite cap, for easy connection to the relay. The makers, Shandon Scientific Co. Ltd., state temperatures may be held constant to within ±0.01°C. **CPE 1484**

Plate heat exchanger

A plate heat exchanger offered by De Laval is claimed to require less steam, refrigeration and water than
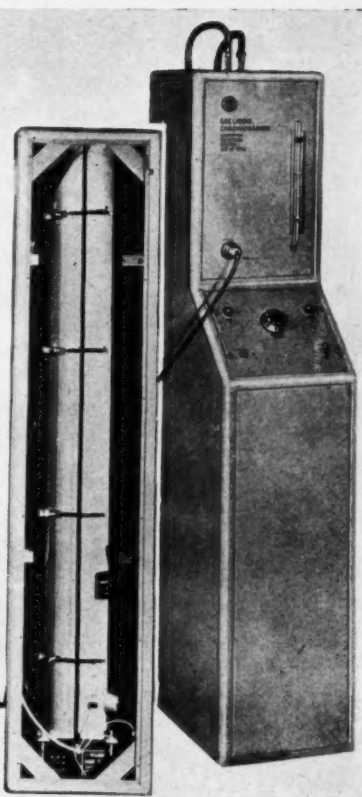
current types. Heat transfer is said to be fast and the unit requires little attention. The design allows installation in a minimum of space.

The plates are of heavy-gauge stainless steel, with highly polished finish. They will retain their shape even when exposed to high liquid pressure; powerful flanges increase rigidity.

Heavy rubber gaskets, set in deep grooves, are fixed by a new gasket cement. The backs of these grooves form rounded ridges which fit against the gaskets in the adjoining plates, which ensures effective tightening and protection of the gasket. A diagram of the flow of liquids through the plate heat exchanger is shown on the right. **CPE 1485**
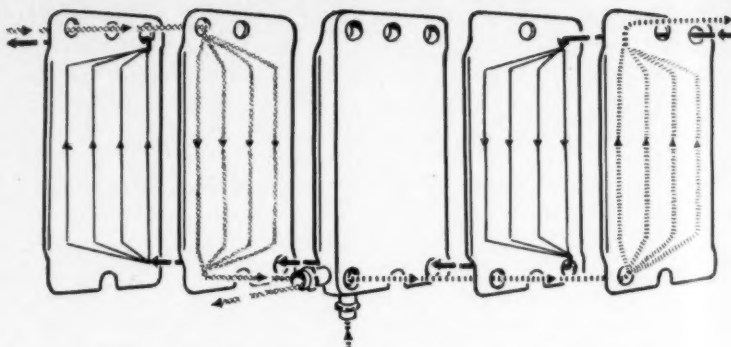

Diagram of the flow of liquids through plate heat exchanger.

Indicating temperature controller

A new indicating temperature controller has been introduced by Honeywell Controls Ltd.

Designed for heating and cooling operations, it controls and indicates temperatures in plating baths, driers, etc.

A sensitive, remote-bulb, liquid-filled thermal system operates a single-pole, double throw micro-switch which can either open or close a circuit on temperature rise.

A selection of ranges is available from −50 to +1,200°F.; Centigrade scales are also available. Both case and capillary are fully compensated for ambient temperature variations. The set point can be changed by means of a knob on the front of the case and both the indicated temperature and set point are made visible by magnifying windows.

The steel case is equipped with slotted mounting brackets so that the controller can be either surface mounted on a wall or flush mounted in a panel. **CPE 1486**

Indicating temperature controller.

Potentiometric scanning system

A development of potentiometric scanning systems is one which can be used singly to monitor all points. The temperature is indicated on a large dial around the periphery of which are the point numbers. A motorised scanning switch enables the equipment to examine each point in turn and a clear perspex pointer, tipped black, indicates the number of the point under examination. With this equipment it is possible to have a different set point for each of the 50 variables.

Thermocouples are used as the detecting elements and the output voltage of the thermocouple is compared with a stable d.c. voltage by means of a self-balancing servo mechanism. All the thermocouple leads are terminated on a panel at the rear of the equipment, and automatic cold junction compensation is incorporated.

The equipment, which is made by Fielden Electronics Ltd., has three tolerance bands which can be adjusted to required values. Any number of temperature points can be allocated to any of these three bands. This will then enable the variables to give an alarm should they deviate by more than a fixed percentage.

Manual override is possible by means of a handle provided on the front panel of the instrument. This enables any temperature to be indicated at will without waiting for the scanner to reach that point in its normal sequence. **CPE 1487**
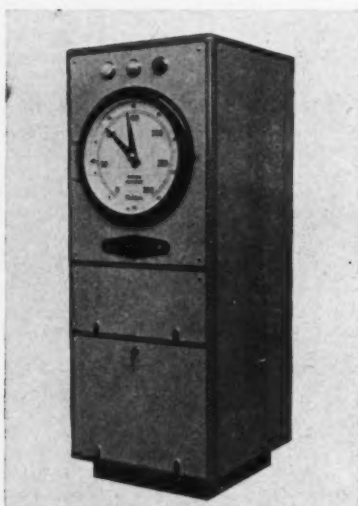
Potentiometric scanning system.

Low-temperature control

West Instrument Ltd. offer a resistance temperature controller and indicator for use in the field of low-temperature control. The new instrument, which is available with stepless, proportioning and on/off control, is suitable for a wide span of operating temperatures, and offers precision control and indication to −100°C.

This compact instrument has a built-in rectifying and stabilising unit fed direct from a.c. mains instead of the usual battery arrangement, which enables it to be used at any time without adjustments to compensate for battery deterioration.

It is fitted with either a three- or four-lead resistance bulb, allowing it to be used at long distances from the point of measurement. **CPE 1488**

Nuclear Fuel Element Developments in France

By F. R. Paulsen, B.Sc., Ph.D., F.R.I.C., F.C.S.

France today has some of the world's best equipped laboratories dealing with reactor fuel elements. Some physical and heat-transfer properties associated with uranium and plutonium fuels are described in this article, particularly mentioning French developments in this field.

NUCLEAR engineers and scientists in France have tackled the problem of the design, construction and operation of reactor fuel elements with skill and imagination. There are many problems still to be solved, of course, but considerable progress has been made already. There are many criteria to be taken into account. For example, in what form must the uranium fuel be used? What must be the dimensions of the fuel pieces? How can one best secure good thermal contact between fuel and the sheath? How is heat best passed on from fuel to coolant? How can one minimise the effects of the dimensional changes which occur during the thermal cycling of fuel elements?

When natural uranium is used there is the problem of ensuring that the maximum amount of heat is removed, and yet at the same time neutrons must not be lost to the U^{238} atoms at a rate greater than can be tolerated. By using enriched fuel, the core is made smaller, and strict neutron economy becomes less important, so that the technologists can accept materials of slightly lower nuclear purity.

During the operative life of the reactor, the U^{235} atoms are gradually used up, and the burn-up life depends upon the degree of enrichment of the fuel. An average rate of burn-up is that which yields about 500 MWD./tonne.

As shown in Fig. 1, for a uranium fuel rod of diameter 15 mm., there is a symmetrical temperature gradient from 600°C. at the centre to 300°C. outside. This temperature gradient results in deformation of the uranium bar, and this effect is assisted by the accumulation of gaseous fission products such as krypton and xenon. When a uranium bar is heated, it expands along the line $A—B$ (Fig. 2). At 670°C. there is a very sudden increase in expansion rate due to phase change; the same occurs again at 770°C. On cooling, the reverse changes occur, but the bar does not return to its original length. Hence, when reheated, it will go through the same series of changes as before, but starting from the point I instead of the point A. The results of many of these thermal cycles is that there is a progressive swelling of the bar. Neutron escape has much the same effect as thermal restraint. Can such

effects be reduced or minimised? Efforts to produce alloys free from this behaviour have shown that the addition of aluminium, molybdenum or zirconium are the most effective in this respect. About 10% of molybdenum is found to retain the gamma form of uranium, stable over a wide range of temperatures, so that the deformations are very much reduced. However, since molybdenum absorbs neutrons, this method of obviating the effects of thermal cycling can only be used with enriched fuels, in which the neutron economy is not so precarious as in natural uranium. It has been found possible to dilute uranium-235 with zirconium, The latter metal, containing 0.7% of U^{235} has been used for fuel rods, showing much the same behaviour as natural uranium, except that the effects of the thermal cycling are negligible and no plutonium is produced in the reactor. As far as France is concerned, such fuel
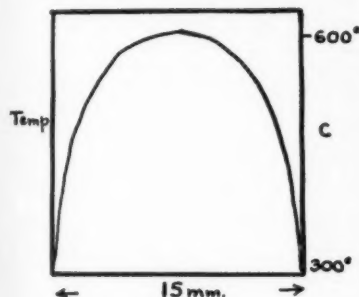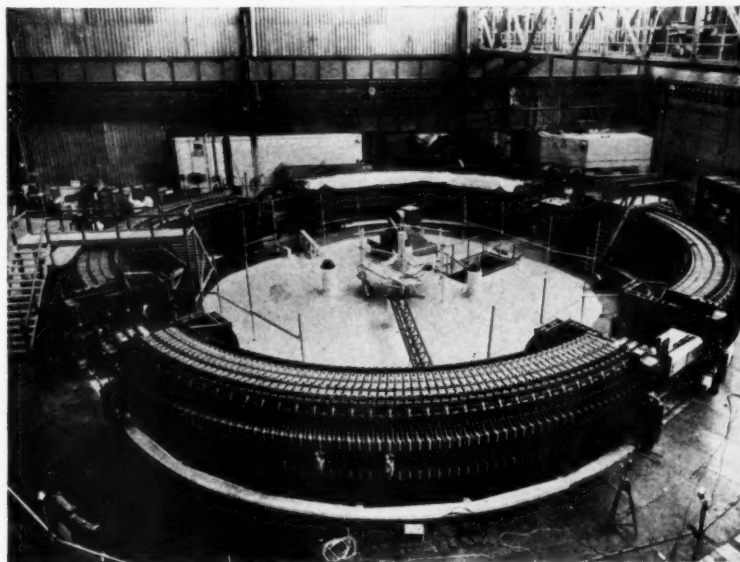

[Photograph by courtesy of the French Atomic Energy Commission

SATURNE reactor at Saclay.

Fig. I.

elements are out of the question for routine production at the moment, since there is no diffusion plant for the manufacture of enriched uranium.

Use of uranium dioxide

Another method of stabilising uranium fuel against thermal cycling effects is to use the uranium in the form of its dioxide, UO_2. This has the great advantage of stability to neutron flux and has a long life. Its thermal stability, however, leaves much to be desired.

The high chemical reactivity of uranium means that it must be protected, during the reactor's life, from materials which might react with it. More especially is this so in the presence of oxygenated materials such as air and water, heavy water, and carbon dioxide, all of which are frequently used as moderators or coolants. The protection of the uranium is usually achieved by the use of a sheath. This has usually been made of magnesium. The principal desiderata for a sheath are gas-tightness, transparency to neutrons, and good conductivity, as well as compatibility with fuel material, coolant and moderator. The metal should also be easily weldable. Magnesium is excellent up to about 500°C., but above this it begins to react with the coolant carbon dioxide. Stainless steel has also proved generally acceptable. Since the sheath has to be able to accommodate itself to dimensional changes occurring in the fuel material, it must be ductile and not brittle. Further, the smaller the degree of enrichment of the fuel, the greater must be the transparency of the sheath

to neutrons. For this reason, the only really acceptable metals for sheathing natural uranium are aluminium, magnesium, beryllium, zirconium and stainless steel. The neutron-absorbing tendency of Inox stainless steel is four times as high as that of aluminium, and so it must be used in thinner gauge. The Inox, in fact, is normally limited to about 1 mm. thickness, for reasons of neutron economy. For obvious reasons, the closer together are the expansion coefficients of uranium and the sheathing metal, the less will be the dangers of deformation due to differential expansion.

Classification of fuel elements

Fig. 3 shows the classification of the various types of fuel elements so far investigated in France. Type I is a simple design, in which natural uranium is enclosed in a magnesium sheath. This is the type of element used in dual-purpose plutonium-and-power-producing reactors at Marcoule. Such an element has its sheath shrunk on to the uranium metal, or else forced into contact by means of gas pressure. The latter method is preferred. Since the fuel element fits into a coolant channel in the graphite moderator (see Fig. 4), with pres-

Fig. 4.

surised coolant gas circulating all around it, the latter must exert a pressure on the sheath both radially and longitudinally. For greater strength, the compression within the sheath around the diameter should be twice that longitudinally. Longitudinal extension may be about 0.03%/cycle, and so may eventually reach about 1%. In order to prevent deformation, there must be a positive grip between the magnesium and uranium. To this end, the finned magnesium sheath has a number of collars on the inner surface (see Fig. 5). When the sheath is compressed on to the uranium metal rod by oil pressure at 3 tonnes/sq.cm., the collars grip the uranium metal in slots, giving good contact.
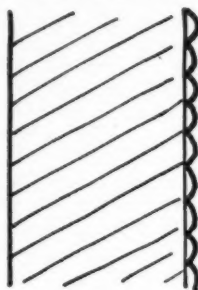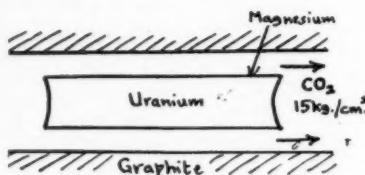
Fig. 5.

Another difficulty experienced in practice was that the uranium, which contained about 3 c.c. of hydrogen per 100 g., liberated hydrogen during service in the reactor. This led to swelling and gas pockets in the fuel elements. Poor thermal contact and excessive deformation resulted. This was overcome by submitting the uranium to vacuum fusion in the high-frequency electric furnace, the hydrogen being drawn off in this way.

Type II element is based upon good contact between the sheath and the fuel by diffusion. This depends upon the interpenetration of the two metals concerned. The temperature at which this commences varies with the pair of metals selected, but is about 600°C. in the case of the zirconium-uranium system. Since this temperature will also obtain in the reactor, the penetration will continue during service, so that corrosion will occur. However, it is possible to perform the diffusion at a considerably higher temperature during manufacture, so that subsequent diffusion becomes less important. The formation of the diffusion layer is shown in Fig. 6. The diffusion method of securing good contact is particularly applicable where the fuel used is highly enriched uranium in a matrix (Type II). A good method of
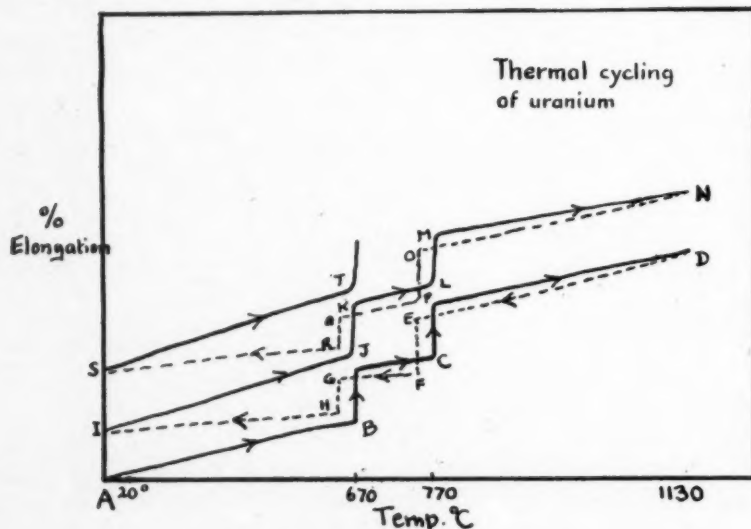
Fig. 2. Thermal cycling of uranium.
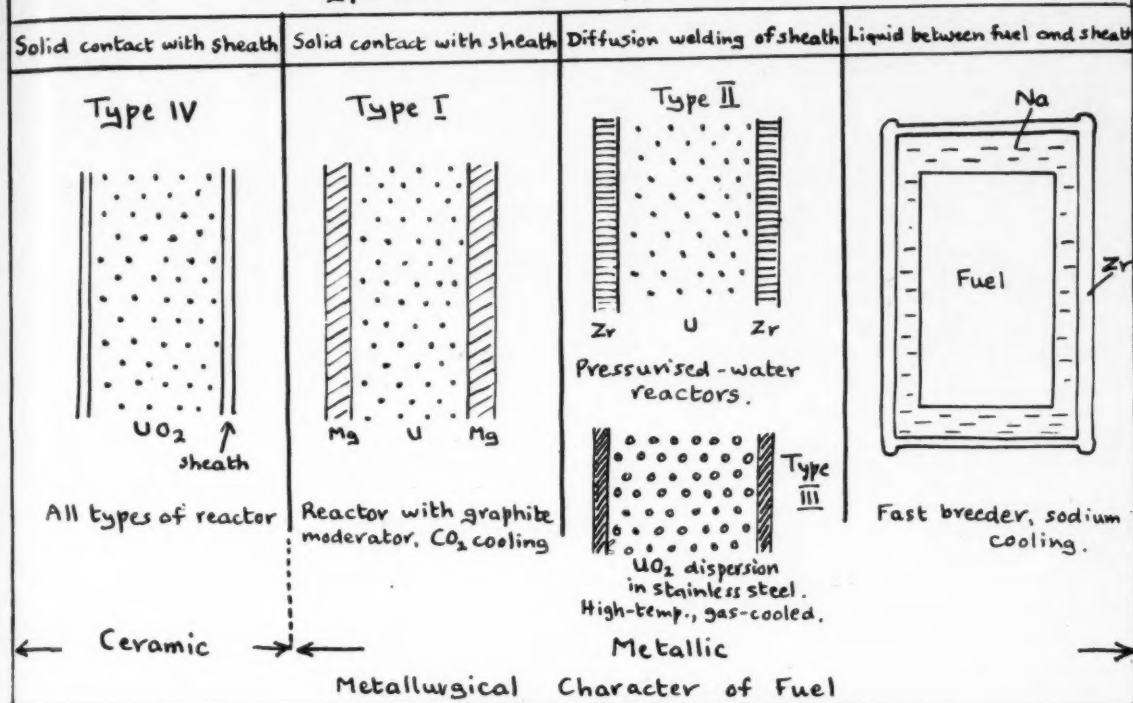
Type of Heat Transmission

Fig. 3.

manufacturing this type of fuel element is to encase the uranium in a zirconium tube and then to pass this through rollers (Fig. 7) until the requisite diameter is attained. The diffusion process actually starts during this rolling. Similar methods can be applied for uranium dioxide which has been ensheathed in zirconium (Type III).

In Type IV the ceramic uranium oxide, UO_2, is enclosed in a metal sheath. Because of the absence of corrosion, and consequent long time in use and small chance of failure, this type of element is particularly favoured for propulsion units. This is, of course, important in ships and submarines, where the changing of fuel

Fig. 6.

rods while at sea would be inconvenient. The chief disadvantage of elements of Types III and IV is their high cost. One popular form of the ceramic oxide type of element consists of a tube of zirconium filled with pellets of the sintered uranium oxide, about 10 mm. in diam. and 10 mm. high. The small size of the pellets ensures good heat transfer and so prevents fusion in use. Bunches of such composite rods can be clipped or tied together, a bunch being held in each channel in the moderator mass.

Type V is one based on the use of liquid sodium as the heat-transfer medium. The fuel is fitted into a zirconium sheath, the intervening space being filled with sodium. This type of element is very good for recycling purposes, the fuel being easily removed. Thus the dismantling and re-assembly are easy.

Plutonium as nuclear fuel

Naturally, consideration has been given in France to the use of plutonium as a nuclear fuel. The only fissile nuclei made in bulk are Pu^{239}, U^{233} and U^{235}. In France, there is up to the present almost no U^{233} available, so that the choice must fall on either U^{235} or Pu^{239} or both. In order to

start a cycle, the reactor must be fuelled with natural uranium. Good neutron economy will then make possible the manufacture of Pu^{239}. The question then arises, 'Is it better to prepare the more efficient enriched fuels by adding U^{235} to natural uranium, or to use Pu^{239} in place of U^{235} for this?'

The factors to be considered are many. Firstly, preparation of U^{235} in

Fig. 7.
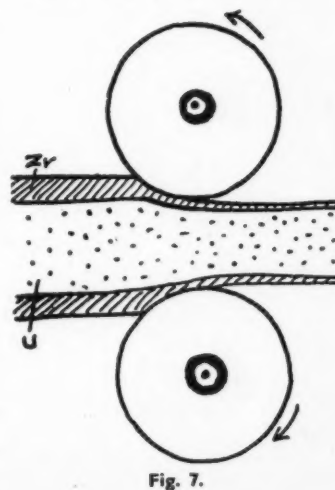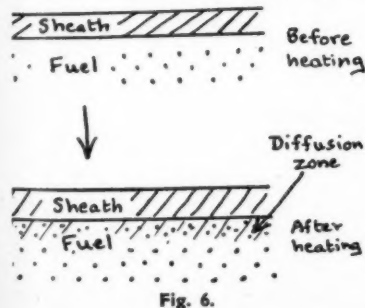
bulk requires a vapour diffusion process for the separation of the isotopes from the natural metal. Such a plant has so far not been built in France, although plans are well ahead for one.

Another important consideration is that the properties of plutonium, especially the nuclear properties, are still not fully known. Again, all plutonium production in France is set aside for military purposes. However, the situation as regards the availability of plutonium should change in due course. With the rapid expansion of the French nuclear power programme, the amount of plutonium produced will probably create a supply exceeding the military requirements. When this time comes, plutonium could conceivably be used as a fissile material for reactors.

In the United Kingdom, the nuclear power production by 1965 should reach 6,000 Mw. installed, giving 3 to 4 tonnes of plutonium p.a. By the same time, France should produce 900 Mw. of power, or 0.5 tonne of plutonium p.a.

Phase changes

While the phase changes which occur during the thermal cycling of uranium are a source of embarrassment to those responsible for the design, manufacture and service behaviour of uranium fuel elements, the situation when plutonium is used could be infinitely worse, as this element exhibits many more phase changes, as Table 1 shows. These changes are to be compared with those for uranium in Table 2.

Table 2

Form	Heat absorption in cals/g. atom
α ↓ β ↓ γ ↓ Liquid	674
	1,131
	4,700

The particularly striking feature is the strong heat change accompanying the interconversion of the α and β forms of plutonium, and the low temperature at which this occurs. Plutonium, although having a comparatively low conductivity for heat, is nevertheless markedly metallic. The filling of the inner electronic shells as we pass through the elements from francium to americium is shown in Table 3.

The reason for the large number of allotropes in the case of plutonium lies in the fact that the $5f$, $6d$ and $7s$ electron shells lie very close together in energy levels, so that the electron transitions are easily effected. With temperature rise, the change in atomic radius of uranium is slight, whereas in plutonium such changes are great. The curves for the atomic volumes of the lanthanons and the actinons are strikingly similar, but neptunium and plutonium occupy anomalous positions. Uranium-235 and plutonium-239 show very similar cross-sections for the absorption of neutrons:

$$U^{235} \qquad Pu^{239}$$

Thermal neutrons:
0.02 EV. $\sigma = 650$ 1,025
Fast neutrons:
1 MEV. $\sigma = 1.30$ 1.85

This means that the combustible geometry is roughly the same for both nuclides, and the fuel rods can be about the same dimensions in both cases. In fact, if each of these fissile forms is diluted with nine times its weight of aluminium, and then sandwiched as a thin layer between aluminium, it is found that the composite plates, made with similar dimensions, behave in almost exactly the same way.

Solid solutions

Again, plutonium and uranium form a complete series of solid solutions above 600°C., so that mixtures are possible with any proportions. This structural compatibility ceases at lower temperatures, however, the equilibrium diagram being very complex.

The addition of 1% of Pu^{239} to U^{238} gives a useful matrix, and this is compatible with metals such as aluminium, beryllium, magnesium and zirconium. Aluminium and zirconium are especially suitable for this fuel matrix, and the resultant alloy can be just as easily fabricated as the aluminium or zirconium metal alone.

The nuclear characteristics of plutonium are not particularly favourable. Of the neutrons reaching the Pu^{239} nuclei, 65% are effective in promoting fission, and the other 35% will convert the plutonium into the higher isotopes, Pu^{240} and Pu^{241}. This means that the maximum proportion of neutrons which can perform fissions in plutonium is 65% and, for this reason, the plutonium is not a very good fuel material.

On the other hand, fission by fast neutrons yields 2.2 to 2.5 neutrons/fission in the case of U^{235}, but 3.0 in the case of Pu^{239}. It may be, then, that the future for plutonium fuel lies in the development of fast reactors. Summarising, it can be stated that there is no fundamental difficulty attending the metallurgy and the fabrication of plutonium. As far as thermal reactors are concerned, the technological difficulties of plutonium are not insurmountable, but the nuclear properties are not too favourable. Further, the development of fast reactors is not sufficiently advanced to make plutonium a very likely fuel

Table 1

Form	Temperature in °C.	Heat absorption in cal./g. atom	Structure
α ↓	125	1,200	Monoclinic
β ↓	213	140	?
γ ↓	314	180	Orthorhombic
δ ↓	464	Less than 40	Face-centred cubic
δ′ ↓	485	380	?
ε ↓	640	530	Body-centred cubic
Liquid			

Table 3

	5f	6d	7s	Valencies	Allotropes
Francium	0	0	1	1	-
Radium	0	0	2	2	-
Actinium	0	1	2	3	-
Thorium	1	1	2	4	-
Protoactinium	2	1	2	5	-
Uranium	3	1	2	3 4 6	3
Neptunium	4	1	2	3 4 6	3
Plutonium	5	1	2	(3) (4) 6	6
Americium	6	1	2	3	3

on the large scale in the immediate future. The fast breeder, *Rapsodie*, will give the French scientists the experience which may in time change this situation.

Saclay fuel element laboratory

The question of long burn-up time has been thoroughly studied at Saclay. It has been found that, with a suitable molybdenum-uranium alloy, the energy liberated from fission can be raised to 4,000 Mw./tonne. With high-temperature, gas-cooled reactors in mind, there has been extensive searching for suitable fuels. Such a fuel must be of melting point above 2,000°C., chemically and thermally inert, crystalline, and isotropic. So far, the best answer to the problem has been found in uranium dioxide. This has a melting point of 2,800°C., density of 10.97, its crystalline lattice is cubic and stable, and the material is very resistant to attack by water and by carbon dioxide. Unfortunately, at 1,000°C., its thermal conductivity is only 0.005 cal./sec./sq.cm./°C., and this limits the rate of heat dissipation. It is fairly easily fabricated, and can be made into plates, tubes, etc. Further, it can be used in the form of dispersions in ceramic materials. As prepared by the reaction of uranium trioxide with hydrogen at 400°C., it is pyrophoric, but higher temperatures of preparation yield a less reactive material with a surface area of 1 sq.m./g. This is actually an optimum value, as is shown in Fig. 8, which shows how the formula for the oxide varies when the oxide is heated in a mixture of hydrogen and nitrogen.

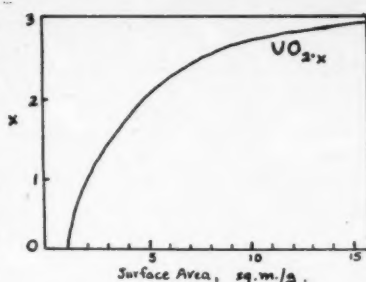The greater deviations from the stoichiometric formula UO_2 are

Fig. 8.

obtained with greater surface area. The oxide powder is fabricated by powder metallurgy methods. It is sieved to 30-mesh, compressed at 5 tonnes/sq.cm., and heated at 200°C. in cracked ammonia. The addition of several per cent. of water vapour favours the attainment of high density in the product. As has been seen already above, the effects of irradiation, liberation of fission gases and high temperatures all combine to break up the uranium fuel rods, and this applies also to the sintered oxide, although the damage is much smaller. For this reason, good sheathing is required even when UO_2 is used.

Besides uranium dioxide, the two uranium carbides, UC and UC_2, have been investigated as possible fuel materials. The lower carbide, UC, has the more favourable properties. Its melting point is 2,500°C., its density is 13.63, its lattice is a face-centred cubic one and its thermal conductivity is 0.045 cal./sec./sq.cm./°C. This carbide shows a good corrosion resistance, even towards carbon dioxide, but unfortunately it is hydrolysed by water above 200°C. It is made by sintering a mixture of

uranium and carbon, in a double-effect pressurised process, at 200 kg./sq.cm., and after 4 hr. a density of 13.6 is attained.

Coolants

The various coolants which have been investigated all give rise to corrosion problems with the fuel cans to various degrees. Using aluminium, beryllium, zirconium, magnesium and stainless-steel cans, the gases hydrogen, helium, air and carbon dioxide have been tested as coolants, the thermobalance being applied as a delicate detector of corrosion. As might be expected, whatever the sheathing material, air and carbon dioxide prove the most corrosive. Magnesium proved satisfactory up to 400°C., even though it develops a surface oxide film from the reactions $Mg + CO_2 = CO + MgO$, and $2 Mg + CO_2 = 2MgO + C$. Aluminium has too low a melting point to prove of much value. The purity of zirconium samples varied so widely that up to now sufficiently accurate data have not been obtained. Beryllium has its corrosion rate limited by an oxide film, formed in the same way as with magnesium. Stainless steel proved suitable up to 600°C., but above this temperature it is less reliable, since it starts to react with carbon dioxide to form iron carbides.

It is clear from these descriptions that French nuclear workers have made a determined attack on the many problems which face those who seek the ideal fuel elements for future reactors.

The writer wishes to acknowledge with gratitude the help and information which he gained from French workers at Saclay and elsewhere.

PLASTICS

(*Concluded from page 137*)

used, is satisfactory for all but oxidising acids and aliphatic solvents. It is applied in sheet form. Hard rubber linings are more resistant than soft rubber, but are more difficult to apply.

PVC is applied as a plastisol and fused *in situ*. Its main use is in plating and pickling tanks.

Asphalt is very cheap and is used for acids and salts. It cannot be used for organic solvents.

Epoxy resins have good resistance to salts and to non-oxidising acids. They do not have such good resistance to solvents as do phenolic and furan resins.

Furan resins have a very wide range of use. With the exception of

chlorine and chlorine bleaches, aniline and certain acid combinations, they can be used at elevated temperatures. Both the latter materials are thermosetting resins which, when cured, will operate at higher temperatures than would be safe with thermoplastic materials. They are supplied as viscous liquids. After mixing with fillers and a suitable catalyst, the liquid sets to an infusible, insoluble solid.

A similar position occurs with mortars and cements. The main use is with acid-proof masonry. The most important materials for joining bricks and tiles are sulphur, phenolic, epoxy and furan resins. Sulphur has poor resistance to alkalis and polar solvents. Phenolic resins have poor resistance to alkalis. Epoxy resins are not used with oxidising acids, and are not so

solvent-resistant as phenolics. Furan cements are very versatile. The field here is not so great as in the previous applications, but here too it is expected that sulphur and silicate cements will give way to the more chemical- and water-resistant plastics.

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[4] I.C.I. private communication.
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[6] Hogberg, *Modern Plastics*, 1955, **33**, 150.
[7] Vincent, *Plastics Today* (*I.C.I.*), 1960, **3**, 13.
[7] Gourley and Jones, *Plastics*, 1956, **21**, 353.
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New Books

Cathodic Protection. Its Theory and Practice in the Prevention of Corrosion. By J. H. Morgan. Leonard Hill Ltd., 9 Eden Street, London, N.W.I. Pp. xviii + 325 + 189 figures, 30 plates and 24 tables. Foreword by J. T. Crennell. 57s. 6d. net.

Although the basic principle of the cathodic protection of metals has been known for over 100 years, the use of the method on a large scale has been developed only in the last 30 years. The practical engineering side of the subject has been expanded rapidly in the last 10 to 15 years. Many technical and theoretical papers have appeared in the world literature and symposia have been held, but hitherto there has been no textbook on the subject, except the one by Pritula that was translated into English and published by the D.S.I.R. The publication of the book by Mr. J. H. Morgan is therefore most welcome.

The author has undoubtedly brought to his task a thorough knowledge of the fundamental principles of electrochemistry and corrosion, but he has done much more than this. His experience in the practical application of cathodic protection has enabled him to deal comprehensively with the engineering aspects.

Of the 11 chapters in the book, the first is concerned with electrochemistry of corrosion and with the theory of cathodic protection, the tenth deals with instruments and the last with the economics of cathodic protection. The remainder of the book is taken up mostly with practical details of the engineering application of cathodic protection.

Electrochemical principles

The first chapter gives a clear and sufficiently detailed description of the electrochemical principles, well illustrated by the use of diagrams of the circuits involved and of the relationships between electrode potential and current density. There is a brief account of the influence of sulphate-reducing bacteria but, while this is quite sound, the statement on p. 20 that '. . . the inoculated electrode will be more base than the sterile one' is certainly not always correct.

Chapter 2 deals with the methods of measuring electrode potential, the geometry of electrodes, ' potential surveys,' the important subject of the proper location of reference half-cells,

current density requirements in different conditions and with the important function of protective coatings in conjunction with cathodic protection. On p. 45 there is an important and welcome, though brief, discussion of the possibility of partial protection by the use of relatively low current densities.

In Chapter 3 the author describes the necessary information relating to resistivity of electrolytes and of soils, with methods of measurement and the mathematical theory needed to understand this aspect of the subject. Chapter 4 deals with sacrificial anodes, including choice of metal, design, the mechanism of their action and the economics of their use. In Chapter 5 a similar discussion is given for the use of impressed current, the choice of power system, consumable as compared with ' permanent ' anodes and again with economics.

Buried structures

Chapter 6 is devoted to the protection of buried structures, perhaps the largest field of application of cathodic protection to date. Theoretical formulae are given for the necessary basic calculations of the required working voltage in the case of short or long pipelines, with a clear indication of the importance of a thorough knowledge of the geometry of the system. After describing the practical measurement and analysis of potentials along pipelines there is a discussion of the requirements for pipe networks, wells, piles, electrical earthing devices and storage tanks.

The rapidly expanding field of application of cathodic protection for structures in sea-water is the subject of Chapter 7. After a reference to the properties of sea-water as an electrolyte, in relation to its corrosive action on metals, the author discusses the protection of steel and aluminium by the use of sacrificial anodes and by impressed current. The design and engineering of schemes for protecting static and floating structures are described and a section is devoted to the protection of ' active ' ships' hulls.

In Chapter 8 there is a most interesting account of the methods now available for the protection of structures, *e.g.* tanks, containing hot or cold water and other electrolytes such as sea-water. Ballast tanks, pipelines carrying water and chemical plant all receive attention. Some mathematical

analysis of the problems involved and much engineering detail are given in this chapter.

The difficult but important problems of stray current and ' interference ' corrosion are discussed in Chapter 9. The various sources and types of interference are described and methods for counteracting these effects are given. In a short section headed ' cathodic corrosion ' on p. 272 a brief reference is made to the corrosion in a buried structure arising from the currents flowing in the ground as a result of the application of cathodic protection in a neighbouring structure. It is surprising that no reference is made here to the Joint Committee on the Co-ordination of the Cathodic Protection of Buried Structures that is operating in Britain to establish agreed procedures for achieving the good neighbourliness that is essential in a highly industrialised country.

The last sentence on p. 272—' Soils and water may generally however prove susceptible to such a criterion ' is an example of the occasional lapses in grammar and construction that occur. On p. 2 we find ' dependant ' instead of ' dependent ' and on p. 144 (line 4) ' the ground will be at equi-potential. . . .' Something seems to have gone astray on p. 253 (line 6) while on p. 259 (lines 7 and 8) the sentence ' The total permissible . . .' the word ' swing ' could relate to ' potential change,' ' conductor,' 'Act,' ' tramway ' or ' railway construction.' Presumably ' swing ' is here the cathodic protection engineer's common jargon for ' potential change '! On line 9 from the bottom on p. 259 ' call ' should read ' called.' On p. 275, Table XV, the potentials of all the reference half cells are given negative signs. This is an unfortunate departure from the convention used in the book—a convention that is generally accepted in Britain and has been encouraged elsewhere.

Apart from these occasional lapses the book is easy to read and with a reasonable amount of effort should be understood by the professional engineers and scientists for whom it is written.

There is no doubt that the author and the publishers have performed a valuable service in making this book available. Copious and clear illustrations are given throughout the text, which is easy to read. All who are concerned with the use of cathodic protection should read the book.

F. WORMWELL,
Corrosion Group,
National Chemical Laboratory.

Company News
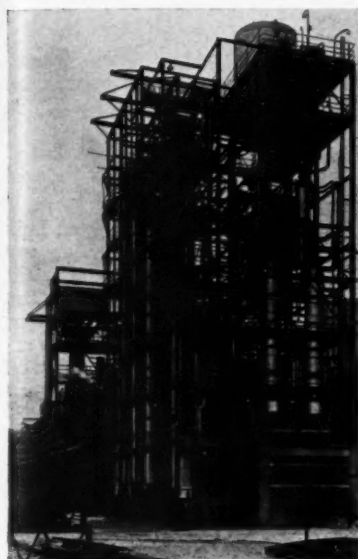
General view of the A.P.V. benzole refinery.

Benzole fractionation

A new, continuous, benzole refining plant, designed and constructed by the chemical engineering division of the A.P.V. Co. Ltd., has been put on stream at the Scunthorpe coke oven and chemical plant of the Appleby-Frodingham Steel Co. This plant is the first one in Britain to produce nitration-grade boiling-range benzole and toluol, 2° xylol and 160 to 190° naphtha continuously from crude coke-oven benzole. The design throughput is 5.5 million gal. p.a. An advance in the benzole refining field is the operation of five continuous fractionating columns in series.

In a test run it was established that at a throughput rate of over 650 gal./hr. of crude benzole the refinery produced the above products with a steam consumption of less than 11.8 lb./gal. of crude. Subsequent operation showed a reduction in this figure.

This is the second benzole refining unit supplied to the Appleby-Frodingham Steel Co. by A.P.V. The first, erected in 1940, processed over 38 million gal. of crude benzole and has now been superseded by this latest plant of twice the original capacity.

Scale models

A special feature in the handling of the contract for a tar oils plant placed with Whessoe by the South Eastern Gas Board for ordnance wharf is the use by Whessoe of scale models of equipment layout and piping for speed and convenience. The basic design of this continuous process plant for the extraction of tar acids and bases from coal-tar fractions is by the Gas Board, while engineering design, procurement and erection are being handled by Whessoe.

Ceramics expansion

Full-scale production of precision ceramics components for military and industrial applications has been started by Minneapolis-Honeywell Regulator Co., U.S.A. The line of close-tolerance ceramics includes ceramics-to-metal seals for use in connectors, headers and other electronics components; small precision ceramics parts that serve as electrical insulators, rigid mountings or spacers, and piezo-electrical transducers that convert mechanical energy to electrical energy (or *vice versa*) in a variety of applications. The custom-tailored parts are designed for use in the aircraft and missile, electronics, machine tool, computer manufacturing, electrical equipment and other industries.

Pipework engineering division

A new division has been formed within Stewarts & Lloyds, the steel tube company. This is the pipework engineering division which will be responsible for the making and marketing of all forms of manipulated pipework.

It will be under separate management with its own sales, engineering and manufacturing departments and will command the services of teams of engineers, designers and craftsmen. Engineers who are specialists in manipulated pipework have been appointed to the sales organisations at branch offices and they will work in direct association with the new division's sales and design offices in Birmingham and Glasgow.

Fertilisers in Northern Ireland

I.C.I. Ltd. is joining with W. & H. M. Goulding Ltd. in the manufacture and supply of fertilisers in Northern Ireland, and is to acquire from W. & H. M. Goulding Ltd. a 51% holding in Richardsons Chemical Manure Co. Ltd. and Ulster Manure Co. Ltd. These companies supply, from their factories at Belfast and Londonderry, most of the fertiliser requirements of Northern Ireland.

It is the intention that Richardsons Chemical Manure Co. Ltd. shall build a new factory at Belfast to make concentrated complete fertilisers. It is expected that the capacity of the new factory will be adequate to supply the Northern Ireland requirements of these fertilisers for some years to come.

Electronic gauges

Following a recent visit to Norway by the export sales manager of Firth Cleveland Instruments Ltd., A/S. Garek of Oslo have been appointed Norwegian representatives for the Gilbarco-Firth Cleveland electronic tank contents gauge. One of their senior engineers will shortly be attending a maintenance and servicing course at the Firth Cleveland instruments factory at Treforest, Glamorgan.

This new appointment is additional to the existing arrangements between Simmonds Aerocessories Ltd., and Firth Cleveland Instruments Ltd., and A/S. Haneborg & Fleischer of Oslo.

Firth Cleveland Instruments Ltd. manufacture the electronic tank gauge and ancillary equipment under licence from the Gilbert & Barker Manufacturing Co., U.S.A.
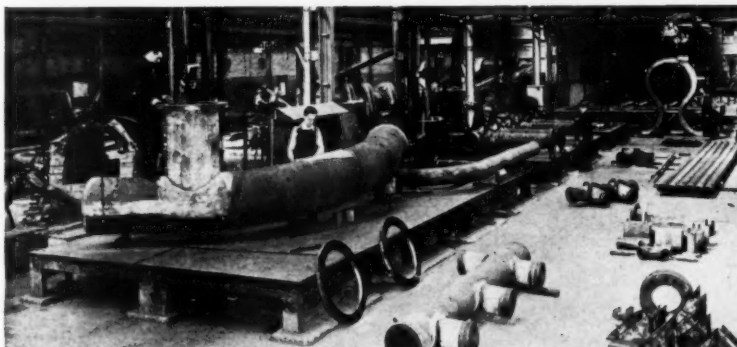
Manipulated high-pressure pipework being assembled at Stewarts & Lloyds.

World News

BRAZIL

Refinery

John Thompson (Wolverhampton) Ltd. recently received a large contract. Valued at £116,130, the new contract was obtained through the company's membership of BREFCON, the British consortium formed 18 months ago for the purpose of supplying plant for the Petroleo Brasileiro S.A. (Petrobras), Brazil.

Foster Wheeler Corporation, of New York, are the engineering contractors in association with Foster Wheeler Ltd., of London, for the Petrobras refinery and, from them, the Wolverhampton company received a contract to manufacture rotating disc contactors.

GREAT BRITAIN

New pipeline

Esso Petroleum Co. announce that an agreement has been concluded with I.C.I. Ltd. for the supply of ethylene direct from the Esso refinery at Fawley to the new Severnside works of I.C.I. in south Gloucestershire.

Permission is now being sought from the appropriate authorities to lay a pipeline between Fawley and Severnside which is estimated to cost about £800,000. The pipeline would be the first of its kind in Great Britain to link physically an oil refinery and a large chemical plant, more than 70 miles apart, for the direct supply of intermediate raw materials.

The pipeline will be buried to a minimum depth of 2 ft. 6 in. and its route would cross several railways, roads, rivers and canals. It will be of welded construction and fully protected against corrosion. It is hoped that construction will commence towards the end of the year and be completed by the end of 1961.

DOMINICAN REPUBLIC

Detergent factory

A factory for detergent manufacture has been set up by the Dominican Republic firm of Jaboneria Lavador. Final experiments have already been made with new equipment before production is started on a commercial scale.

It is stated that the company used to use 70% foreign raw materials up to two years ago, but now it uses 80% home-produced raw materials. The first aim of the enterprise was to make soaps capable of competing with imported goods. At present, some 15,000 cakes of washing soap and 2,000 cakes of toilet soaps are produced each month.

The present capital of Jaboneria Lavador C. por A. is $300,000, which has been increased by $50,000 to cover the cost of the new extensions being undertaken. Future plans of the firm include the manufacture of toothpastes, brilliantines, shaving soaps and cosmetics. For this, machinery costing a further $50,000 is to be acquired.

CEYLON AND RHODESIA

Institution of the Rubber Industry

Authority has been given and the first steps taken in establishing sections of the Institution of the Rubber Industry in Ceylon and Rhodesia. The new sections will work to promote the development of polymer science and technology, to encourage technical education and provide a means of association between persons engaged in the rubber industry in those countries.

This was confirmed at a meeting of the Council of the Institution held recently in London when applications received from provisional committees set up in Colombo and in Bulawayo were unanimously approved.

The Council welcomed these new developments which will provide those engaged in the rubber and allied industries in Ceylon and Rhodesia with all the advantages and benefits that derive from a scientific society, such as lecture programmes and training facilities in polymer science and technology leading to diploma examinations and awards.

These developments follow closely on those in South Africa where branches of the Institution were set up in Johannesburg and Durban in January 1959.

HUNGARY

Argon gasworks

An argon gasworks has been built at Pét Nitrogen. A new shop was erected on the premises to house the high-capacity chemical equipment necessary for the manufacture of argon gas. The argon is produced in several phases from the so-called blown-off gas produced during the manufacture of fertilisers. It has a purity of 99.9% and is suitable for industrial purposes.

NORWAY

Kjeller reactor

The planning of the new atomic reactor at the Institute of Atomic Energy at Kjeller near Oslo is about to be concluded, and it is expected that construction will commence some time in the spring. The new reactor, JEEP II, will cost 10 million kroner (£500,000), and will be completed in a couple of years.

JEEP II will relieve JEEP I, which was completed in 1951 and has been run as a joint Dutch-Norwegian undertaking. JEEP II is designed with a special view to experimental physics, and it will also have a greater isotope production capacity.

Corrosion Exhibition

Plans are being made to ensure that London's Olympia is the focus of the anti-corrosion drive in 1960. Participation by the largest and most representative companies in the 'anti-corrosion' industry will make the Corrosion Exhibition 1960 the biggest and most comprehensive display of its kind. Already two-thirds of the space in the Empire Hall, Olympia, has been reserved—and the exhibition does not open until November 29.

Paints, plastics, rubbers, plating, resistant metals and alloys, cathodic protection, glass-lined plant, inhibitors, temporary protectives and protective tapes are among the products which will be on show. Corrosion science will be represented by the Department of Scientific and Industrial Research who will feature the work of the Corrosion Group at Teddington. The D.S.I.R. stand at the 1959 Corrosion Exhibition attracted much attention.

Among well-known companies which have reserved stands are British Oxygen, Shell Chemicals, I.C.I., Albright & Wilson, Dunlop, Yorkshire Imperial Metals, Geigy, Enamelled Metal Products, Ciba and Hercules Powder Co.

The Corrosion Exhibition will open at 11 a.m. on Tuesday, November 29, and will remain open for the next three days—until Friday, December 2. It will be held at the Empire Hall, Olympia, London. Enquiries for remaining stand reservations should be made immediately of the Organiser, Leonard Hill House, Eden Street, London, N.W.1 (Euston 5911).

Personal Paragraphs

★ **Sir Alexander Fleck** has been appointed president of the Society of Chemical Industry for 1960-61 in succession to **M. E. J. Solvay.** Sir Alexander will be installed as president at the annual meeting of the society at Bristol in July.

★ **Mr. B. Heath,** managing director of Powell Duffryn Carbon Products Ltd. and a director of other companies in the group, has relinquished his Powell Duffryn appointments. Following his resignation, **Mr. R. Turner,** acting managing director of Powell Duffryn Technical Services Ltd., has joined the board of Powell Duffryn Carbon Products Ltd. as deputy chairman, and **Mr. F. W. Stokes,** a director and the present works manager of the company's factory at Hayes, has been appointed general manager.

★ **Mr. T. Lockett,** a former chief chemist of the Middlesex main drainage department and a past president of the Institute of Sewage Purification, died in February at the age of 73. He was well known in the field of sewage purification. Following research work carried out at Manchester with Fowler and Ardern, he discovered, in 1914, the activated sludge process of sewage purification. This discovery revolutionised sewage treatment and the process has been adopted by all the largest public health authorities in the world during the last 40 years. At the time of his death he was editor of the journal and proceedings of the Institute of Sewage Purification, an honorary post he had held for nearly 21 years.

K. R. Sandiford.   C. J. Smith.

★ **Mr. K. R. Sandiford** has joined Hagan Controls Ltd. as general manager. Since 1954 he has been chief instrument engineer of the development and engineering group of the U.K.A.E.A.

★ **Mr. R. N. Millar,** a director of General Electric Co. Ltd., has been appointed managing director of the company's engineering group. He will have overall responsibility for the whole of the company's activities in the heavy electrical, mechanical and nuclear engineering fields. He was appointed general manager of Fraser & Chalmers engineering works, Erith, in 1958 and a year later became a director of the G.E.C. **Dr. K. J. Wootten** becomes general manager of G.E.C. Erith works. He joined the company in 1955 and in April 1958 became manager of the atomic energy division. **Mr. C. J. O. Gerrard** becomes deputy general manager. He has been with the company since 1934. Since 1958 he has been in charge of the company's engineering sales in the Southern England area. **Dr. H. K. Cameron** becomes mana-

C. J. Carter.   K. J. Wootten.

ger of the atomic energy division. He is honorary secretary for home affairs of the Society of Chemical Industry.

★ New appointments and changes to the board of directors of the Fairey Co. Ltd. were announced recently. **Mr. G. W. Hall** continues as chairman of the company, but relinquishes his appointment as managing director. **Mr. C. H. Chichester Smith** is appointed managing director. **Mr. C. C. Vinson** is appointed an additional director and **Mr. L. S. Dawkins** is appointed an additional director, retaining his appointment as secretary.

★ **Mr. C. I. Rutherford,** director of I.C.I. fibres division since 1958, has been appointed production director with effect from April 1. He succeeds **Mr. W. F. Osborn** who is retiring after 34 years with the company and its predecessors.

★ **Mr. J. B. Kitchin** has been appointed personnel director of I.C.I. plastics division in succession to **Dr. R. G. Heyes,** who has combined the

L. S. Dawkins.   C. H. Chichester Smith.

responsibilities of personnel and production since 1956. Mr. Heyes remains as production director. Mr. Kitchin has been deputy head of the central work study department.

★ **Dr. C. J. Dadswell** relinquished the office of managing director of Davis & Lloyd (1955) Ltd. and has been appointed chairman. **Mr. C. Muirhead,** O.B.E., took over the office of managing director. Dr. Dadswell is a director of English Steel Corporation Ltd. and Mr. Muirhead is a special director.

★ **Mr. C. J. Carter** retired last month from the directorship of John Thompson-Kennicott Ltd. Of his more than 50 years' service with the company, 41 have been concerned with water-treatment systems and the manufacture of plant to carry them out. He is succeeded by **Mr. W. J. Jeavons** who has been with the company for 15 years.
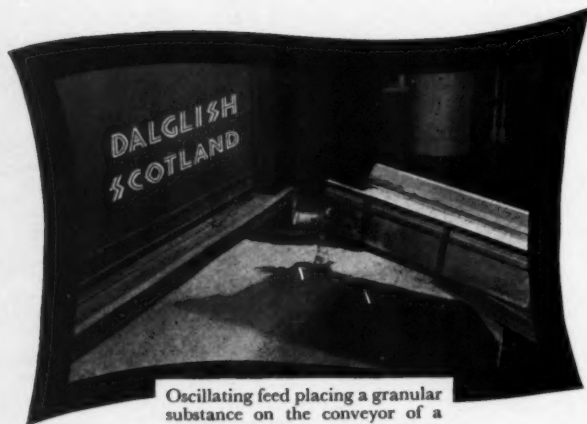
★ **Mr. P. Colebrook,** managing director of Pfizer Ltd., has also become managing director of Kemball, Bishop & Co. Ltd. He succeeds **Mr. W. W. Muir** and **Mr. R. F. Kemball,** joint managing directors of Kemball, Bishop & Co. Ltd. Mr. Muir is remaining on the board in an advisory capacity. **Mr. J. Platt,** formerly a planning executive of Pfizer Ltd., has been appointed general works manager of Kemball, Bishop.

★ **Mr. P. Wrightson,** O.B.E., managing director of Head Wrightson & Co. Ltd. since 1955, has been appointed vice-chairman and managing director.

★ **Mr. C. J. Smith** has resigned his appointment with Dorr-Oliver Co. Ltd. and has joined Eimco (Gt. Britain) Ltd. as deputy manager, filter division. He is honorary recorder of the Chemical Engineering Group of the Society of Chemical Industry.

★ **Mr. E. Tate,** assistant sales manager of Coalite & Chemical Products Ltd. (Coalite division), has been appointed by the National Carbonising Co. Ltd. to the position of sales manager for Rexco smokeless coal.
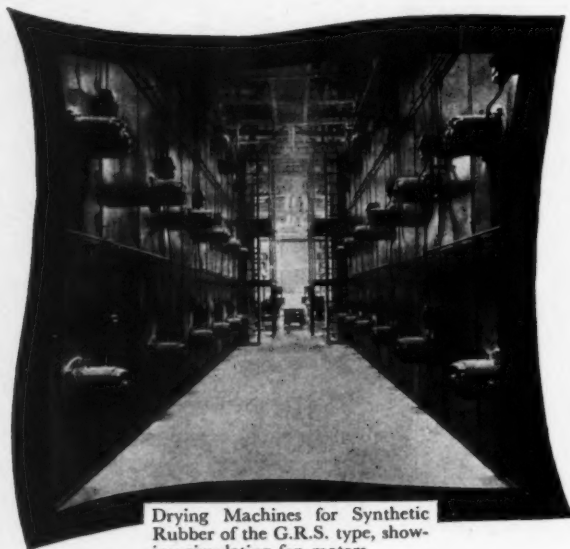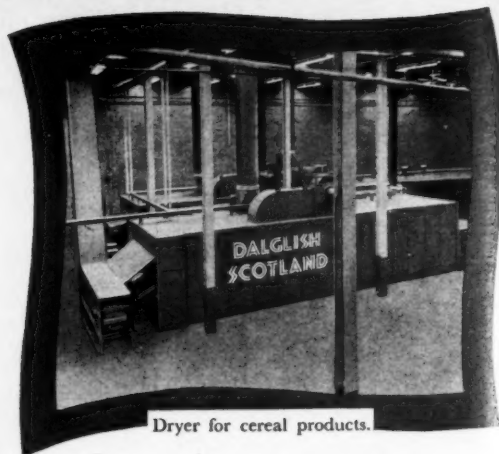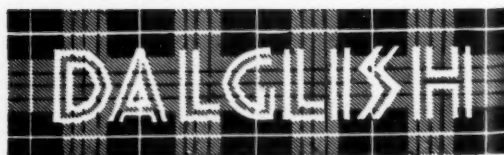
CPE Diary

APRIL 19 TO 22 International Symposium on the **metallurgy of plutonium—session on nuclear fuels** in Grenoble, France. Organised by the Société Francaise de Metallurgie and the French Atomic Energy Commission. Details from the Société, 25 rue de Clichy, Paris.

APRIL 20 TO 21 Symposium on **advances in the chemical analysis of fertilisers, soils and plants** at Church House, London, S.W.1. Organised by the Society of Chemical Industry. Information from the hon. secretary of the agricultural group of the society, Dr. P. W. Arnold, Rothamsted Experimental Station, Harpenden, Herts.

APRIL 21 TO 22 Conference on the **training of the industrial physicist** in Birmingham. Organised jointly by educational group and Midland branch of the Institute of Physics. Details from the institute, 47 Belgrave Square, London, S.W.1.

APRIL 22 TO 23 Symposium on **fertiliser analysis** at the Church House, London, S.W.1. Organised jointly by the Fertiliser Society and the Society for Analytical Chemistry. Information from the secretary, Fertiliser Society, 44 Russell Square, London, W.C.1.

APRIL 25 TO 29 European **Fluid Power** Conference at the Empire Hall, Olympia, at the same time as the **Compressed Air and Hydraulics** Exhibition. Information from the conference secretary, Compressed Air and Hydraulics, St. Richard's House, London, N.W.1.

APRIL 25 TO 30 Fourth biennial **Production** Exhibition and the British Productivity Council's conference on **Productivity, Men and Methods** in the National Hall, Olympia. Information from the secretary, Production Exhibition, 11 Manchester Square, London, W.1.

APRIL 26 TO 29 Course for directors and senior executives at the **Radioisotope** School. Organised by the U.K.A.E.A. Details from the school, Wantage Radiation Laboratories, Wantage, Berks.

APRIL 26 TO 28 Second European symposium on **chemical reaction engineering (section on non-conventional reactors)** in Amsterdam, Netherlands. Organised by the European Federation of Chemical Engineering. Details from P. J. Hoftyzer, Centraal Laboratorium, Staatsmijnen, Geleen (L.), Netherlands.

APRIL 27 TO MAY 6 **Fuel Efficiency and Power for Industry** Exhibition at the National Hall, Olympia. There will be a series of technical meetings on the **selection of fuel-using equipment and power plant.** Information from the Secretary, Institute of Fuel, 18 Devonshire Street, Portland Place, London, W.1.

MAY 2 TO 3 Conference on **reactions between complex nuclei** at Gatlinburg, Tennessee, U.S.A., organised by the American Physical Society. Details from Dr. R. S. Livingstone, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.

MAY 2 TO 4 Meeting of the nondestructive testing group of the Institute of Physics and the Société Francais de Metallurgie on the **relationship between structure and physical properties of materials.** Details from the Secretary, Institute of Physics, 47 Belgrave Square, London, S.W.1.

MAY 2 TO 13 Course on **advanced chemistry** at the Isotope School, Wantage. Organised by the U.K.A.E.A. Details from the school, Wantage Radiation Laboratories, Wantage, Berks.

MAY 3 TO 13 **Mechanical Handling** Exhibition at Earls Court, London, S.W.5. Organised by *Mechanical Handling*, the monthly journal. Details and tickets from H. A. Collman, Mechanical Handling, Dorset House, Stamford Street, London, S.E.1.

MAY 4 TO 6 Annual conference of the **Institution of Plant Engineers** at the Grand Hotel, Scarborough. Information from the institute, 2 Grosvenor Gardens, London, S.W.1.

MAY 4 TO 6 International Symposium on **Distillation** at Brighton, organised by the Institution of Chemical Engineers. Programme and registration forms from the secretary of the institution, 16 Belgrave Square, London, S.W.1.

MAY 10 TO 13 Symposium on **fuel element fabrication with special emphasis on cladding materials** in Vienna. Organised by the International Atomic Energy Agency. Details from I.A.E.A., 11 Karntner Ring, Vienna 1, Austria.

MAY 23 TO JUNE 1 **First plenary session of ISO/TC/85 on nuclear energy** and current sessions of subcommittees 1, 2, 3 and 4 in Geneva. Organised by the General Secretariat of the International Organization for Standardization. Details from H. G. Lamb, American Standards Association, 70 East Street, New York 17.

MAY 29 TO JUNE 11 Special meeting of **Iron and Steel Institute,** including a joint meeting with the Associazione Italiana di Metallurgia, in Italy. Details from H. Cleere, Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1.

MAY 30 TO JUNE 2 First International **Pipes and Pipelines** Exhibition at Earls Court, London, S.W.5. Details from the organisers, Scientific Surveys Ltd., 97 Old Brompton Road, London, S.W.7.

MAY 30 TO JUNE 3 Jubilee conference of the Textile Institute on **fibre science.** Details from the institute, 10 Blackfriars Street, Manchester 3.

MAY 31 TO JUNE 3 Meeting of the Society of Physical Chemistry on the **structure of graphite and kinetics of its reactions** in Paris. Details from G. Emschwiller, secretary general, Society of Physical Chemistry, 10 Rue Vauquelin, Paris 5e, France.

JUNE 5 TO 9 World Power Conference —sectional meeting on the **methods for solving power shortage problems including conventional nuclear sources** in Madrid, Spain. Details from the secretary, British National Committee, World Power Conference, 201-202 Grand Buildings, Trafalgar Square, London, W.C.2.

JUNE 27 TO JULY 8 International **course in French on nuclear energy,** designed for senior engineers and technical industrialists, at the Centre d'Etudes Nucleaires at Saclay, France. Details from O.E.E.C. European Nuclear Energy Agency, 38 Boulevard Suchet, Paris 16.

Orders and Contracts
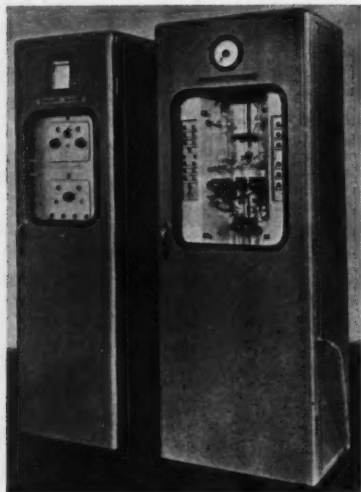
The titromatic analyser recently sold by Electronic Instruments Ltd. to the Canadian Aluminium Co. Ltd.

Titromatic analyser

The first Canadian order for the titromatic analyser, manufactured by Electronic Instruments Ltd., valued at over $10,000, has been received from the Canadian Aluminium Co. Ltd.

The analyser is intended to assay the aluminium content and the free alkali of five separate ore plant streams. To perform this, it automatically carries out a double end-point titration with two added reagents on each of the five streams.

The Canadian requirements created a particularly difficult problem because of the corrosive nature of the reagents required in the assay of the aluminium content of ore. Special arrangements for flushing and mechanically brushing the electrodes after each titration were made.

Exhibition contract

Mr. P. Schilling, chairman of the export committee of S.I.M.A. (Scientific Instrument Manufacturers' Association of Great Britain) signed in February the contract in Moscow whereby 34 British scientific instrument makers will show and demonstrate the latest equipment in Moscow at the Polytechnic Museum from June 18 to 29.

This exhibition of British scientific instruments is entirely financed by the industry itself through the charges to the exhibitors. It is believed to be the first British collective private enterprise exhibition ever to be held in Moscow.

The Russians are very interested in many of the advanced types of instrumentation which exhibitors will be showing and have agreed to consider purchasing those which they require at the exhibition.
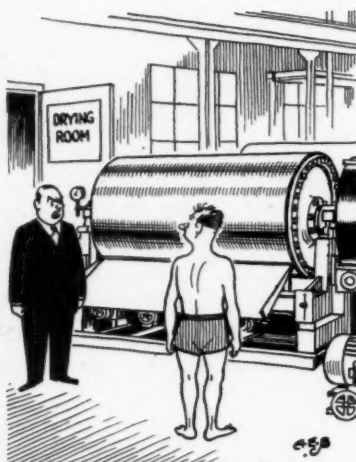
The exhibition will be attended by a large number of representatives from all the academic, medical, industrial and scientific establishments including laboratory and research institutions throughout the Soviet Union, who will receive special invitations to attend.

Briquetting plant

The chemical engineering division of W. C. Holmes & Co. Ltd. have received an order, value about £31,000, for the installation of a complete briquetting plant at the Kingston-on-Thames 'B' power station of the Central Electricity Generating Board.

This plant has been designed in collaboration with Neldco Processes Ltd. and Conreur Ledent et Cie of France, who will supply the press. The plant will produce 10 tons/hr. of ovoids, using grit taken from the station's dust collection system, mixed with fine coal. Liquid pitch will be used as the binder. The ovoids will be burnt on standard chain-grate stokers.

The plant is expected to be in operation before the end of 1960.

Comical Engineering Corner

" I DON'T CARE IF YOU DID GET SOAKED ON THE WAY TO WORK, HIGGINS — "

Hydrogen plant

Brockville Chemicals Ltd. of Canada has awarded a contract to P.G. Engineering Ltd. and their associated company Power-Gas Canada Ltd. for the complete design, construction and commissioning of a hydrogen plant at a new works now in course of erection near Maitland, Ontario. The plant will produce 15 million cu.ft./day of hydrogen, mainly for ammonia synthesis, using as a feedstock natural gas delivered by pipeline from Western Canada.

The plant is scheduled for completion early in 1961 and the value of this contract is approximately $1.8 million.

Water-treatment contract

An agreement was recently signed between Head Wrightson & Co. Ltd. and the Belco division of Bogue Electric Manufacturing Co. of U.S.A., which will enable Head Wrightson to design, engineer and build water-treatment and trade-waste-disposal plants throughout the world, excluding the North American continent.

Hobbing machines

Dowding & Doll Ltd. have received orders from the U.S.S.R. valued at about £47,000 for 20 Dowding *Universal* hobbing machines complete with all equipment, including tangential feed.

Water-softening plant

The North Lindsey Water Board has awarded William Boby & Co. Ltd. the contract, valued at £18,500, for extensions to the existing Boby automatic base-exchange water-softening plant for the Board's pumping station at Barrow-upon-Humber. The extension will bring the plant's capacity up to 150,000 gal./hr.